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HUNTINGTON BEACH SEAWATER DESALINATION PLANT
PRESSURE SURGE ANALYSIS
POSEIDON RESOURCES CORPORATION

Prepared for

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SUMMARY

This report describes the results of an analysis of the surge pressures created by the operation of the three (3) proposed Huntington Beach seawater desalination plant booster pump stations (i.e., BPS#1 at the desalination plant, BPS#2 near the San Joaquin Reservoir and BPS#3 at Coastal Junction). It evaluates the effect of these pressure surges on the 48-inch (or 42-inch) Poseidon Resources Corporation (PRC) pipeline (between the desalination plant and the OC-44 transmission main), the OC-44 transmission main, East Orange County Feeder No. 2 (EOCF#2), the Irvine Cross Feeder (ICF), the Orange County Feeder Extension (OCF Ext.), Coastal Supply Line, and the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains.

This report also describes several surge protection recommendations and some hydraulic modifications to the existing system to protect the water transmission and distribution system from pressure transients created by the operation (i.e., power failure and startup) of the booster pump stations. The surge computer model of the system described above was setup based on data gathered from the steady state hydraulics computer model developed by Carollo Engineers and information (e.g., pipeline plan and profile drawings) supplied by Metropolitan Water District of Southern California, Municipal Water District of Orange County, Costa Mesa County Water District, Tri-Cities Municipal Water District, and other agencies. Flow Science believes that if the recommended surge protection and hydraulic modifications (as stated in this report) are implemented, the integrity of the proposed and existing distribution system would be protected. However, this analysis was conducted at a preliminary stage and the assumptions and results of this analysis should be verified once more planning and design of the proposed pump stations and pipelines have been completed.

A table showing predicted maximum, minimum and steady state operating pressures with surge protection installed is provided in Appendix A of this report.

The results of the system analysis show that upon loss of power to the booster pump stations, a low-pressure (i.e., pressure drop) wave is predicted to propagate out from the discharge side of each booster pump station and into the associated discharge pipelines. As they travel toward the reservoirs, demand locations and booster pump stations, the low-pressure waves cause the pipeline pressure to fall. Simultaneously, a pressure upsurge wave is predicted to propagate out from the suction side of BPS#2 and BPS#3.

Following loss of power to BPS#1, the minimum HGL elevation drops below the crown elevation of the PRC pipeline sufficiently far that a vapor condition is generated in most of the pipeline. The duration of the low pressure, which is independent of the diameter (i.e., 42 or 48 inches) that will be selected for the PRC pipeline, is predicted to be long enough for vapor cavities to form.

When the PRC pipeline is re-pressurized by a reflected waterhammer wave, any vapor cavities that are formed will collapse, and in the process could produce extremely high local pressure spikes that may damage the pipeline, resulting in premature corrosion and the development of leaks. When subjected to a negative pressure, a leak could become a source of pathogen intrusion. If the piping does not have sufficient strength to withstand a full vacuum, the pipeline could collapse under such low pressures.

Due to the pressure upsurge wave created by the loss of power to BPS#2 the maximum HGL elevation on OC-44 is predicted to exceed the set point of the pressure relief valve at STA. 254+00. The opening of the pressure relief valve will create a pressure drop wave that, in combination with the pressure drop wave from BPS#1, will reduce the pipeline pressure sufficiently far that a vapor condition is generated at the PRC Pipeline inter-connection, between some of the existing air and vacuum valves on OC-44, and near STA. 453+08 on OC-44. In addition, the existing air and vacuum valves are predicted to slam shut upon re-pressurization, which could damage the floats and create more waterhammer pressure waves.

The results of the analysis also show that the minimum HGL elevation is predicted to drop below the crown elevation at highpoints on EOCF#2, the ICF, the OCF Ext. and the Aufdenkamp transmission main.

To eliminate large negative pressures and the possibility of vapor cavity formation in the delivery pipeline system described above, surge protection is recommended as follows:

- Install a minimum 2,940 ft^3 (e.g., diameter = 12 ft and length = 26 ft) horizontal pressurized surge tank on the <u>discharge</u> side of BPS#1. The surge tank should contain 30 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

- Install a minimum 1,890 ft^3 (e.g., diameter = 10 ft and length = 24 ft) horizontal pressurized surge tank on the <u>suction</u> side of BPS#2. The surge tank should contain 70 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

Note that it is not necessary to install a surge tank on either the discharge side of BPS#2 or the suction and discharge sides of BPS#3.

In addition to the surge tank protection described above, vacuum relief valve protection is recommended as follows:

- Install minimum 6-inch and 4-inch diameter vacuum relief and air release valves, each with a controlled venting feature, at STA. 453+08 on OC-44 and at STA. 1194+94 on

EOCF#2 (see Figure 1 in this report for locations), respectively, in place of the existing combination air and vacuum valves at these locations.

- Install a minimum 4-inch diameter combination air and vacuum valve at STA. 9+29 on the ICF, if not already installed at this location.

A vacuum relief-air inlet valve in combination with a small orifice diameter air release valve (e.g., APCO S-1500C, or equivalent) or a single body valve (e.g., Vent-O-Mat) are examples of valves that control the venting of the air from the system upon re-pressurization. Alternatively, a combination air valve with a slow closing surge check feature could be used.

Each vacuum relief valve should be duplicated to provide redundancy in case of valve failure or removal for servicing. A regular vacuum relief valve maintenance program should be put in place to ensure that the valves are always in good working order.

The above recommended surge protection will protect the pipelines following power failure to the booster pump stations if the diameter of the pipeline from the desalination plant to OC-44 is either 42 inches or 48 inches.

The pumps at BPS#1 should be ramped up to full speed in 45 seconds or longer and each subsequent pump start should be lagged by at least 90 seconds. In addition, the pumps at BPS#2 and BPS#3 should be ramped up to full speed in 30 seconds or longer and each subsequent pump start should be lagged by at least 90 seconds.

Necessary Hydraulic Modifications to the Existing Distribution System

To facilitate the delivery of desalination plant product water via the proposed booster pump stations and existing pipelines, Flow Science believes that the following hydraulic modifications to the distribution system, which are unrelated to surge protection, are necessary:

- Install a 42-inch diameter bypass with a hydraulically operated isolation valve (e.g., ball, plug or cone valve) around the closed pressure control valves at STA. 254+00 on the OC-44 transmission main. The pressure control valves at this location reduce the pressure to an HGL elevation less than 438 ft when the Diemer WTP is supplying flow to the OC-44 transmission main (i.e., under the existing non-pumping mode), but will be closed when the booster pump stations are operating.

- Lockout the pressure relief valve at STA. 1090+95 on EOCF#2 when BPS#2 is in operation so that the pressure relief valve will not open when the HGL elevation exceeds the set point elevation of 485 ft at this location. Note that this existing pressure relief valve is required when the Diemer WTP is supplying flow to EOCF#2 between Coastal Junction and the ICF (i.e., under the existing non-pumping mode).

- Install a pressure control valve with a downstream set point less than 480 ft on the EOCF#2 between BPS#2 and the ICF (i.e., just upstream of STA. 1237+79 on EOCF#2). This valve will prevent the over-pressurization of the ICF (i.e., it will prevent the HGL elevation in the ICF from exceeding 485 ft) and air gap spillage at the San Joaquin Reservoir when BPS#2 is in operation.

INTRODUCTION

Poseidon Resources Corporation (PRC) is designing a 50 MGD seawater desalination plant for Huntington Beach and has retained Carollo Engineers to evaluate the hydraulics of the pipeline delivery system. Normally most of the flow supplied to the pipelines analyzed herein originates from the Metropolitan Water District of Southern California (i.e., from Diemer WTP) via Coastal Junction. Under the proposed operation, product water from the desalination plant will supply the majority of water demand in the pipeline delivery system described below.

A booster pump station (BPS#1) will be installed at the desalination plant and will deliver flow through a proposed 48-inch (or 42-inch) diameter pipeline that will be constructed between the desalination plant and the OC-44 transmission main. The alignment of this pipeline has yet to be finalized.

A second booster pump station (BPS#2) is proposed for installation at the location where the OC-44 transmission main and East Orange County Feeder No. 2 (EOCF#2) intersect (i.e., near the San Joaquin Reservoir) and will deliver water to Coastal Junction and the Irvine Cross Feeder (ICF). A pressure control valve will be installed on EOCF#2 upstream of STA. 1237+79 between BPS#2 and the ICF to prevent the over-pressurization of the ICF when BPS#2 is in operation. Product water will be supplied to the Orange County Feeder Extension (OCF Ext) and the Coastal Supply Line via the ICF.

A third booster pump station (BPS#3) will be installed at Coastal Junction, which will be closed to EOCF#2 when BPS#3 is operating, to increase the pressure sufficiently to supply water (in addition to that supplied by the Diemer WTP) to the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains.

Flow Science is completing the part of Carollo Engineers hydraulic evaluation that involves the analysis of the possible pressure surges that could be created in the delivery pipeline system by the operation (i.e., power failure and startup) of the proposed booster pump stations.

This report therefore addresses the possible pressure surges that may occur in the delivery pipeline system as a result of the loss of power and startup at BPS#1, BPS#2 and BPS#3. In addition, this report describes the methods of analysis, the results obtained, and the recommendations derived from the analysis. The report was prepared by Flow Science Incorporated of Pasadena, California acting under agreement with Carollo Engineers of Santa Ana, California.

The report begins with a general discussion of typical surge and waterhammer problems that can occur within this type of system. This is followed by the results of an analysis of the possible surge conditions in the system, and the development of specific design recommendations for surge protection.

WATERHAMMER AND PRESSURE SURGES

Waterhammer and pressure surges in piping systems are created when a change in the pipeline flow rate occurs. The source of the change in flow rate may be normal operations, such as the starting or stopping of a pump, or the opening or closing of a valve. In addition, sudden and unplanned changes in flow can occur as a consequence of loss of power to pumps or a pipeline failure.

When a pumping system is shut down as part of normal operations, or by power failure, the hydraulic grade line (HGL) downstream of the pump station falls very rapidly. The rapidity of the pressure drop is controlled primarily by the polar moment of inertia of the pump/motor system. If the inertia is high the HGL falls slowly, but for most small pumping units it drops to the suction water elevation, or below, in a second or so. For in-line pumps, the fall in downstream HGL is generally mitigated by a concomitant rise in the upstream HGL as the upstream flow is brought to rest. The rapid pressure drop (created by loss of power to the pump) travels out along the downstream pipeline as a pressure drop wave (i.e., low pressure wave) moving at a speed of 1000-4000 ft/sec, depending upon the pipe material and dimensions.

Since the steady flow HGL slopes down toward the pipeline discharge point, and in many cases the pipeline profile rises toward the discharge point, at some location along the profile the dropping HGL may fall below the invert of the pipe, thereby creating a vacuum in the pipe. If the HGL falls more than 34 ft below the pipe crown, the vacuum created will equal the vapor pressure of the water and it will begin to boil at ambient temperature. Once boiling occurs a vapor cavity will form at the crown of the pipe and the pressure downsurge wave will continue propagating along the pipeline leaving behind a pipeline under vacuum and filled with boiling water. When the downsurge wave reaches the discharge point, or other constant pressure point, it is reflected as a repressurization wave. This wave travels back up the pipe, removing the vacuum and stopping the boiling. When there is an extensive vapor cavity it will tend to accumulate at some point in the pipeline (usually at a break in the slope or local high point) and collapse explosively. The net result is a localized region in the pipe that is subjected to an extremely high impulsive pressure — a waterhammer. As the repressurization wave finally returns to the pump station it may close the pump check valve suddenly and create an additional waterhammer.

There are therefore two sources of waterhammer associated with power failure to pumps — one from vapor cavity formation, the other from the return flow reaching the pump check valve. Maximum pressures generated by the first mechanism (vapor cavity collapse) cannot be predicted for two reasons. First, it is almost impossible to predict where the vapor cavity collapse will occur and second, the speed of collapse cannot be accurately predicted. Waterhammer resulting from pump check valves closing can be predicted quite accurately provided vapor cavity formation does not occur in the pipeline.

The second major source of waterhammer in pipelines is valve operations. If a valve is opened too quickly, the pipeline pressure will drop suddenly. The sudden pressure drop propagates upstream from the valve site as a pressure downsurge wave that may cause the HGL to drop below the pipeline crown and form a vapor cavity, just as for pump failure pressure loss. On the other hand, closing an open valve too quickly can create a sudden pressure rise as the flow kinetic energy is converted to pressure energy, just as the flow reversal at a pump station can cause a waterhammer at the check valve.

Control of waterhammer induced by valve operations is simple—the rate of valve motion is adjusted to an appropriate speed. Prevention of inadvertent rapid valve motion is attained by using gear-operated valve mechanisms. In addition, pressure relief valves may be installed to release any untoward rise in pressure.

Control of waterhammer arising from pump operations can be accomplished by one of four basic methods.

1. Increase the rotating inertia of the pump/motor system. This is seldom practicable on long pipelines (in excess of 2000 ft) because of the size of flywheel required. In addition, it is undesirable to increase the inertia when variable frequency drives (VFDs) are employed as it will increase power consumption when the pump changes speed.

2. Install vacuum break (air inlet) valves on the pipeline. These allow air to enter the pipeline whenever the internal pressure falls below atmospheric pressure. Depending on the slope of the pipeline and the initial slope of the hydraulic grade line, they may be required every 500-4000 ft along the pipeline. However, such valves let air into the pipeline and restarting of the pumps and flow must be done very carefully to prevent a line-fill slam. Furthermore, on potable water systems the potential for contamination is created. If the valves are installed on the pipeline within vaults, a vent, with a capacity equivalent to the area of the valve orifice needs to be incorporated into the design of the vault.

3. Install pressure relief/surge relief/surge anticipator valves on the system. These valves open to allow high pressures created in the system to bleed off, usually to the atmosphere. They are most effective when installed at the source of the pressure rise. They do nothing to alleviate low pressure problems and can create more severe low pressure problems if not properly designed.

4. Install a surge tank (either open or pressurized) that will continue flow after the pump has stopped until such time as the flow in the pipeline reverses. For high head systems, closed pressurized tanks containing a partial air fill are appropriate. For low head systems, an open surge tank or stand pipe can be satisfactory.

Analysis of Waterhammer and Pressure Surges

The pressures created by changing flow conditions in piping systems can be determined quite accurately by the application of Newton's Laws of Motion up to the condition where a vapor cavity forms in the pipeline. Flow Science has developed a set of computer programs that solve the waterhammer wave equations (Newton's Laws) for situations involving pump power failure and valve operations. These computer codes, which use the method-of-characteristics solution technique for the appropriate equations, allow computation of the pressure and flow at any point in a distribution network at prescribed times after power failure or valve operation. The codes have been developed over a period of 30 years and have been extensively tested and independently verified in the field and by comparison with codes developed by others.

PHYSICAL FACILITIES

The interconnection of the Poseidon Resources delivery pipeline with the local water distribution system is shown in Figure 1. This figure shows that a booster pump station (BPS#1) will be installed at the 50 MGD seawater desalination plant proposed for Huntington Beach. It will deliver flow from the plant through a proposed 48-inch (or 42-inch) diameter pipeline that will be constructed between the desalination plant and the OC-44 transmission main. The alignment of this pipeline has yet to be finalized. BPS#1 will take water from a wet well with an approximate water surface elevation of 10 ft.

A second booster pump station (BPS#2) is proposed for installation at the location where the OC-44 transmission main and East Orange County Feeder No. 2 (EOCF#2) intersect (i.e., near the San Joaquin Reservoir) and will deliver water to Coastal Junction and the Irvine Cross Feeder (ICF). A pressure control valve (PCV) with a downstream set point HGL elevation less than 480 ft will be installed on EOCF#2 between BPS#2 and the ICF (i.e., just upstream of STA. 1237+79 on EOCF#2) to prevent the over-pressurization of the ICF when BPS#2 is in operation. Product water will be supplied to the Orange County Feeder Extension (OCF Ext) and the Coastal Supply Line via the ICF.

A third booster pump station (BPS#3) will be installed at Coastal Junction to increase the pressure sufficiently to supply water, in addition to that supplied by the Diemer WTP, to the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains.

The length and diameter of each pipeline along with the water levels at Diemer WTP and Bradt Reservoir are shown in Figure 1. The overflow levels at the San Joaquin Reservoir air gap and the Big Canyon Reservoir standpipe are also noted in Figure 1. The surge analysis is based upon system demand data supplied to Flow Science by Carollo Engineers.

There is an existing 4-inch diameter vacuum relief valve at STA. 2048+82 on the OCF Ext and an existing combination air and vacuum valve of unspecified diameter at

STA. 1194+94 on EOCF#2. In addition, a 3-inch diameter combination air and vacuum valve is currently installed at STA. 453+08 on the OC-44 transmission main.

Note that there is both an existing in-line pressure control structure and an existing pressure relief valve installed at STA. 254+00 on OC-44. The 16-inch pressure relief valve is installed on the downstream side of the pressure control structure, which will be closed during pumping. The pressure relief valve is set to open and discharge to waste when the pressure at that location exceeds 180 psi, which is equivalent to an HGL elevation of ~438 ft.

A 42-inch diameter bypass with a hydraulically operated isolation valve (e.g., ball, plug or cone valve) will be installed around the pressure control station at STA. 254+00 on the OC-44 transmission main. The pressure control station at this location currently reduces the downstream pressure to less than 150 psi when the Diemer WTP is supplying flow to the OC-44 transmission main.

The Red Lion pressure relief valve (STA. 1773+82 on the OCF Ext.) will open and discharge to waste when the HGL elevation at that location exceeds 490 ft.

Another pressure relief valve, installed at STA. 1090+95 on EOCF#2, is set to open and discharge to waste when the HGL elevation exceeds 485 ft and Coastal Junction is open to EOCF#2 (i.e., under existing operation). When the booster pump stations are operating, Coastal Junction will be closed to EOCF#2 and the pressure relief valve at STA. 1090+95 on EOCF#2 will be locked out so that it will not open and discharge to waste when the HGL elevation exceeds the set point elevation of 485 ft.

The pressure control structure at Santiago Creek on EOCF#2 was set to reduce the downstream HGL elevation to 675 ft or lower. The two (2) pressure control valves on the Aufdenkamp transmission main are set to reduce the downstream HGL elevation to 475 ft and 440 ft or lower. A 2-inch diameter combination air and vacuum valve is currently installed at the highpoint on the Aufdenkamp transmission main. The Willits Street Pressure Control Structure and Irvine Regulating Structure are set to reduce the downstream HGL elevation to 475 ft and 310 ft (or lower), respectively.

A maximum surge pressure limit of 1.33 times the working (or in some cases static, whichever is greater) pressure of the steel and concrete pipelines was used when developing the surge protection system design recommendations. Therefore, the maximum allowable pressure of the pipelines under surge conditions was conservatively assumed to be equal to the working (in some cases static) pressure of the piping plus a 33 percent surge allowance (based on the working or static pressure).

Using pipe strength calculations supplied by the Metropolitan Water District of Southern California (MWD), Carollo Engineers conservatively established the maximum working (i.e., rated) HGL elevation in EOCF#2 (between the ICF and Coastal Junction) to be 640 ft. A

33 percent surge allowance was conservatively employed when designing surge protection for EOCF#2 even though the MWD calculations show that a 50 percent surge allowance would be acceptable. Drawings supplied by the MWD show that the maximum allowable static HGL elevation in the ICF is 485 ft.

Due to the preliminary nature of the hydraulic study, Carollo Engineers could not supply pump curves and rated characteristics for the booster pump stations. Instead, appropriate pump curves and characteristics were selected by Flow Science to meet the maximum anticipated capacity and pumping head, as specified by Carollo Engineers, for each booster pump station.

The assumed characteristics and number of pumps are shown in Table 1 for each booster pump station. The combined polar moment of inertia (WR^2) of each pump, motor and shaft combination was conservatively estimated from catalog information appropriate to the size of each pump. In addition, it is assumed that a 36-inch diameter swing check valve will be installed on the discharge side of each pump. It was also assumed that the pumps at each booster pump station will be equipped with soft-start motors or variable frequency drives (VFD).

Table 1 – Pump Rated Characteristics

Pump Station	BPS#1	BPS#2	BPS#3
No. Pumps	3	3	3
Rated Flow (gpm)	11,574 (16.7 MGD)	10,505 (15 MGD)	6,442 (9.3 MGD)
Total Rated Head (ft)	415	385	50
Rated Speed (rpm)	1,780	1,780	1,780
Rated Efficiency (%)	84	84	84
Motor hp	1,600	1,600	150
Total WR^2 (lb-ft^2)	602	602	56

Note that the total rated head of the pumps at BPS#1 will be 490 ft if a 42-inch diameter pipeline is installed between the desalination plant and the OC-44 transmission main.

The predicted maximum total steady state output and pressure head at each booster pump station is summarized in Table 2.

Table 2 – Booster Pump Station Steady State Flow and Head

Pump Station	Flow		Head
	(gpm)	(MGD)	(ft)
BPS#1	35,274	50.8	409
BPS#2	32,067	46.2	379
BPS#3	19,878	28.6	48

TRANSIENT ANALYSIS AND RECOMMENDATIONS

The steady state flow conditions together with the system geometry described above, formed the basis for the pressure surge analysis of the pipeline system. Maximum pumping at each booster pump station provided a baseline analysis for the system under worst-case high and low pressure surge conditions. The analysis was performed for both a 42-inch and 48-inch diameter pipeline installed between the desalination plant and the OC-44 transmission main.

48-inch PRC Pipeline

The results of the analysis of the system show that upon loss of power to the booster pump stations, a low-pressure (i.e., pressure drop) wave is predicted to propagate out from the discharge side of each booster pump station and into the associated discharge pipelines. The low-pressure waves cause the pressure to fall in the pipelines as they travel toward the reservoirs, demand locations and other booster pumps stations. Simultaneously, a pressure upsurge wave is predicted to propagate out from the suction side of BPS#2 and BPS#3.

Figure 2 illustrates the predicted maximum and minimum HGL elevations in pipeline graphic path A (i.e., the 48-inch PRC pipeline, see Figure 1) following loss of power to BPS#1 at the desalination plant. It illustrates that the minimum HGL elevation drops below the crown elevation of the pipeline sufficiently far that a vapor condition is generated in the pipeline. The duration of the low pressure is predicted to be long enough for vapor cavities to form.

When the pipeline is re-pressurized by a reflected waterhammer wave, any vapor cavities that are formed will collapse, and in the process could produce extremely high local pressure spikes that may damage the pipeline resulting in premature corrosion and the development of leaks. When subjected to a negative pressure, a leak could become a source of pathogen intrusion. If the piping does not have sufficient strength to withstand a full vacuum, the pipeline could collapse under such low pressures.

It is extremely difficult to calculate the maximum pressure that will occur as a result of a vapor cavity collapse, such as predicted to occur here under the conditions examined. There are two basic reasons for this. The first is that the maximum pressure generated in a vapor cavity is very dependent upon the geometry of the vapor cavity, which cannot always be simulated since the precise location of the cavity collapse cannot be predicted. Second, the size of the cavity formed is very dependent upon the duration of the low pressure condition, the number of boiling nuclei in the water, the temperature of the water, the diameter of the pipe, and the fraction of dissolved gas that exists in the water, most of which are known very imprecisely, if at all.

The Flow Science computer model of transient flows therefore does not compute the maximum pressure that will occur as a result of a vapor cavity collapse. For this reason, the predicted pressure head histories at BPS#1 and at H2ONET Node 9040 (see Figure 1 for this location) on the PRC pipeline, each of which is shown in Figure 3, do not reflect the extremely high local pressures that could be produced when the pipeline is re-pressurized and any vapor cavities that have formed collapse. However, this figure does show that the pressure head at H2ONET Node 9040 is predicted to drop to vapor pressure following loss of power to BPS#1.

The predicted maximum and minimum HGL elevations along pipeline graphic path B (i.e., OC-44) are depicted graphically in Figure 4. Due to the loss of power to BPS#2 the maximum HGL elevation is predicted to exceed the set point of the pressure relief valve at STA. 254+00 on OC-44. The opening of the pressure relief valve creates a pressure drop wave that, in combination with the pressure drop wave from BPS#1, reduces the pipeline pressure sufficiently far that a vapor condition is generated at the PRC Pipeline inter-connection, between some of the existing air and vacuum valves on OC-44 and near STA. 453+08 on OC-44. In addition, the existing air and vacuum valves are predicted to slam shut upon re-pressurization, which could damage the floats and create more waterhammer pressure waves. This figure also shows that the maximum HGL elevation is predicted to not exceed the maximum allowable HGL elevation of the OC-44 (excluding the possibility of vapor cavity collapse).

Figure 5 shows that, if the high pressures in the OC-44 are not reduced, the pressure relief valve at STA. 254+00 is predicted to open and discharge flow from the transmission main. In addition, this figure shows that an existing vacuum relief valve at STA. 453+08 will open approximately 17 seconds after loss of power to the booster pump stations and remain open as the system drains.

The results of the analysis for graphic path C (i.e., EOCF#2) are shown in Figure 6 and illustrate the predicted maximum and minimum HGL elevations following loss of power to the booster pump stations. As shown in this figure, between the ICF and Coastal Junction the maximum steady state HGL elevation is predicted to not exceed the maximum working (i.e., rated) HGL elevation of EOCF#2. This shows that BPS#2 is predicted to not over-pressurize EOCF#2 (between the ICF and Coastal Junction) under steady state operation.

Figure 6 also shows that the minimum HGL elevation is predicted to remain above the crown elevation of the pipeline except near STA 1194+94 and near BPS#2 where the pressure head drops to −18 ft. The maximum pressure in EOCF#2 is predicted to not exceed the rated pressure (based on the rated HGL elevation) by more than 33 percent of the rated pressure. The same is true for the remainder of EOCF#2 between Coastal Junction and the Diemer WTP. If Coastal Junction is not opened to supply the flow demand through the ICF following loss of power to the booster pump stations, the pressure in EOCF#2 between the ICF and Coastal Junction will slowly drop as the system drains.

The rated and steady state HGL elevations coincide in Figure 6 (and some of the figures presented below) because this operating scenario (defined by Carollo Engineers) will result in the worst-case high pressure surges.

Figure 7 shows the predicted pressure traces on the suction and discharge sides of BPS#2 following loss of power to the booster pump stations. The predicted pressure records at OC-39 and STA. 1194+94 are illustrated in Figure 8 and show that the existing vacuum relief valve will open approximately 40 seconds after loss of power to the booster pump stations and remain open as the system drains.

Figures 9 and 10 show, for graphic paths D (i.e., Aufdenkamp Main) and E (i.e., Joint Main, formerly Tri-Cities), respectively, the predicted maximum and minimum HGL elevations after loss of power to the booster pump stations. As these figures show, the maximum HGL elevation is predicted to not exceed the steady state HGL elevation of the pipelines and the minimum HGL elevation is predicted to remain above the crown elevation of the pipelines except at the combination air and vacuum valve on the Aufdenkamp Main.

Figure 11 shows the predicted pressure head traces on the suction and discharge sides of BPS#3 following loss of power to the booster pump stations. The pressure head histories at the highpoints of the Aufdenkamp and Joint transmission mains are depicted in Figure 12.

The predicted maximum and minimum HGL elevations in the ICF (i.e., graphics path F) are depicted in Figure 13. This figure shows that the maximum HGL elevation in the ICF is predicted to not exceed the maximum allowable HGL elevation (i.e., El. 485 ft) and the minimum HGL elevation is predicted to drop approximately 18 ft below the crown elevation of the ICF highpoint (i.e., STA. 9+29). For this analysis, it was assumed that an existing vacuum relief valve was not installed at this location. The pressure head history at the highpoint of the Irvine Cross-Feeder is shown in Figure 12.

Figures 14 and 15 show, for graphic paths G (i.e., OCF Ext.) and H (i.e., Coastal Supply Line), respectively, the predicted maximum and minimum HGL elevations following loss of power to the booster pump stations. As these figures show, the maximum HGL elevation is predicted to not exceed the steady state HGL elevation and the minimum HGL elevation is predicted to remain above the crown elevation of the pipelines with the exception of near the vacuum valve at STA. 2048+82 on the OCF Ext where the pressure head drops to -5 ft.

Figure 16 illustrates the predicted pressure head traces at the Red Lion relief valve (STA. 1773+82) and at an existing vacuum relief valve (STA. 2048+82) on the OCF Ext. and shows that the vacuum relief valve is predicted to open approximately 215 seconds after loss of power to the booster pump stations and remain open as the system drains.

Elimination of large negative pressures and the possible formation of vapor cavities is believed to be essential to the safe operation of this system.

Surge Protection

To eliminate large negative pressures and the possibility of vapor cavity formation in the delivery system it is recommended that a minimum 2,940 ft^3 (e.g., diameter = 12 ft and length = 26 ft) horizontal pressurized surge tank be installed on the discharge side of BPS#1. The surge tank should contain 30 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

It is also recommended that a minimum 1,890 ft^3 (e.g., diameter = 10 ft and length = 24 ft) horizontal pressurized surge tank be installed on the suction side of BPS#2. The surge tank should contain 70 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

Note that it is not necessary to install a surge tank on either the discharge side of BPS#2 and or the suction and discharge sides of BPS#3.

In addition to the surge tank protection described above, it is recommended that minimum 6-inch and 4-inch diameter vacuum relief and air release valves, each with a controlled venting feature, be installed at STA. 453+08 on OC-44 and at STA. 1194+94 on the EOCF#2 (see Figure 1), respectively, in place of the existing combination air and vacuum valves at these locations. A vacuum relief-air inlet valve in combination with a small orifice diameter air release valve (e.g., APCO S-1500C, or equivalent), or a single body valve (e.g., Vent-O-Mat), are examples of valves that control the venting of the air from the system upon re-pressurization. Alternatively, a combination air valve with a slow closing surge check feature could be used.

Also, a minimum 4-inch diameter combination air and vacuum valve should be installed at STA. 9+29 on the ICF, if not already installed at this location.

Each vacuum relief valve should be duplicated to provide redundancy in case of valve failure or removal for servicing. A regular vacuum relief valve maintenance program should be put in place to ensure that the valves are always in good working order.

With the surge tank and vacuum relief valve protection recommended above installed, the results of a power failure analysis, shown in Figures 17 through 24 for graphic paths A through H, indicate that upon power failure to the booster pump stations, the minimum HGL elevation is predicted to remain above the crown elevation of the pipelines except at the location of the vacuum relief valves described above.

These figures also show the predicted maximum HGL elevations in each pipeline following loss of power to the booster pump stations. The maximum HGL elevation is predicted to not exceed the maximum allowable HGL elevation of the pipelines. In addition, the maximum HGL elevations are predicted to remain below the set point HGL elevations for the pressure relief valves at STA. 254+00 on OC-44 (see Figure 18) and at STA. 1773+82 (Red Lion) on the OCF Ext. (see Figure 23). That is, these pressure relief valves will not open with the above recommended surge protection installed.

Following loss of power to the booster pump stations, the maximum HGL elevation in EOCF#2 (between the ICF and Coastal Junction) near BPS#3 is predicted to exceed the rated HGL elevation (i.e., 640 ft), but not the maximum allowable HGL elevation, which was conservatively based on a 33 percent surge allowance instead of MWD's 50 percent surge allowance.

The predicted pressure histories at BPS#1 and H20net Node 9040 (see Figure 1) are depicted in Figure 25 and show that the pressure at BPS#1 drops slowly and that the amplitude of the pressure peaks are progressively attenuated with each pressure wave cycle following loss of power to the booster pump stations. In addition, this figure shows that the pressure is predicted to remain above atmospheric pressure at H2ONET Node 9040.

Figure 26 shows the predicted pressure traces at the pressure relief valve (STA. 254+00) and at the recommended 6-inch diameter vacuum relief valve (STA. 453+08) on OC-44 following booster pump station power failure. The predicted pressure records on the suction and discharge sides of BPS#2 are shown in Figure 27. Figure 28 depicts the predicted pressure head history at the recommended 4-inch diameter vacuum relief valve (STA. 1194+94) and at the OC-39 turnout on EOCF#2. The predicted pressure heads on the suction and discharge sides of BPS#3 are shown in Figure 29 and the predicted pressure head histories in the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains, ICF, and OCF Ext. are illustrated in Figures 30 and 31.

42-inch PRC Pipeline

A transient flow analysis of the system was also performed assuming that the pipeline between the desalination plant and the OC-44 transmission main will be 42 inches in diameter and that the surge protection recommended above is installed. As noted in the Physical Facilities, the total rated head of the pumps at BPS#1 will be 490 ft under this option.

The results of the analysis show that the above recommended surge protection will also protect the pipe system following power failure to the booster pump stations when the pipeline from the desalination plant to OC-44 is 42 inches in diameter. For brevity a detailed discussion of these results is not presented since they are very similar to the results for the 48-inch diameter pipeline, but the graphical results of the analysis are included in this report for completeness.

The predicted maximum and minimum HGL elevations in the pipeline system following loss of power to the booster pump stations are shown in Figures 32 through 39 for graphic paths A through H (see Figure 1). In addition, Figures 40 through 46 illustrate the predicted pressure histories at each of the booster pump stations and in each of the pipelines following power failure.

Unlike the results with the 48-inch pipeline installed, the maximum pressure head is predicted to not exceed the steady state pressure head at BPS#1 following loss of power to the booster pump stations.

PUMP STARTUP ANALYSIS AND RECOMMENDATIONS

Startup of the booster pump stations following resumption of power was analyzed assuming that the recommended surge tank and vacuum relief valve protection was installed and that a 42-inch diameter pipeline was installed between the desalination plant and OC-44. In this analysis, it is assumed that, prior to booster pump station startup, the pressure control structure at Coastal Junction does not open to re-pressurize EOCF#2 and that the PCV between EOCF#2 and the ICF (STA. 1237+79 on EOCF#2) is initially closed, but opens after pump start. In addition, it is assumed that Coastal Junction valves CM-10 and CM-12 will increase the flow from Diemer to the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains to make up for the loss of flow from the desalination plant after booster pump station power failure, but at the same time will maintain an HGL elevation no greater than 675 ft at Coastal Junction. It is also assumed that all demands are shut-off until a pump at each booster pump station comes up to speed. These assumptions result in more severe transient pressures in the pipelines following pump startup than if the demands were initially open.

Figures 47, 48 and 49 show, for graphic paths A and B and ECOF#2 (between the ICF and Coastal Junction), the maximum and minimum predicted HGL elevations following startup at the booster pump stations. The predicted maximum HGL elevations will not exceed the maximum allowable HGL elevations of the pipelines if (1) the pumps at BPS#1 are ramped up to full speed in 45 seconds or longer and subsequent pump starts are lagged by at least 90 seconds, and (2) the pumps at BPS#2 and BPS#3 are ramped up to full speed in 30 seconds or longer and subsequent pump starts are lagged by at least 90 seconds. Following pump startup, the predicted maximum pressure in EOCF#2 is predicted to not exceed the rated pressure (based on a 640 ft HGL elevation) by more than 13 percent, which is less than both the 33 percent surge allowance proposed in this report and the 50 percent surge allowance proposed by MWD. Figures 50 through 52 illustrate the predicted pressure histories at each of the booster pump stations subsequent to pump startup.

The above startup recommendations also apply in the event that a 48-inch diameter pipeline is installed between the desalination plant and OC-44, but for brevity the results of that analysis are not shown here.

In reality, following booster pump station power failure, the pressure control structure at Coastal Junction will eventually open and permit flow from the Diemer WTP to be directed into EOCF#2 toward the ICF and OC-44. Design and operation of the valve structures (i.e., at STA. 254+00 on the OC-44, proposed PCV upstream of STA. 1237+79 on EOCF#2, and the pressure relief valve lockout at STA. 1090+95 on EOCF#2) that will be required to facilitate startup of the booster pump station from the existing operating condition (i.e., delivery of flow from the

Diemer WTP to EOCF#2, ICF, OC-44, OCF Ext. and the Coastal Supply Line) is beyond the scope of this pressure surge analysis. Although it is not anticipated that the surge protection recommendations described above will change as a result of an analysis of this startup condition, it is recommended that such a startup analysis be performed once these design details are more fully developed.

SUMMARY AND CONCLUSIONS

Based on the results of the above analysis, surge protection is required to protect the Poseidon Resources Corporation's proposed 48-inch (or 42-inch) diameter pipeline (between the Huntington Beach seawater desalination plant and the OC-44 transmission main), the OC-44 transmission main, the East Orange County Feeder No. 2 (EOCF#2), the Irvine Cross Feeder (ICF), the Orange County Feeder Extension (OCF Ext.), and the Aufdenkamp and Joint (formerly Tri-Cities) transmission mains. The following recommendations will protect the system from pressure transients resulting from the loss of power to the booster pump stations at the desalination plant (BPS#1) and near the San Joaquin Reservoir (BPS#2) and Coastal Junction (BPS#3).

- Install a minimum 2,940 ft^3 (e.g., diameter = 12 ft and length = 26 ft) horizontal pressurized surge tank on the discharge side of BPS#1. The surge tank should contain 30 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

- Install a minimum 1,890 ft^3 (e.g., diameter = 10 ft and length = 24 ft) horizontal pressurized surge tank on the suction side of BPS#2. The surge tank should contain 70 percent air under steady state flow conditions and be connected to the discharge piping with a 24-inch diameter pipe that produces losses equivalent to three (3) velocity heads for flow both into and out of the tank.

Note that it is not necessary to install a surge tank on either the discharge side of BPS#2 or on the suction and discharge sides of BPS#3.

In addition to the surge tank protection described above, vacuum relief valve protection is recommended as follows:

- Install minimum 6-inch and 4-inch diameter vacuum relief and air release valves, each with a controlled venting feature, at STA. 453+08 on OC-44 and at STA. 1194+94 on EOCF#2 (see Figure 1 in this report for locations), respectively, in place of the existing combination air and vacuum valves at these locations.

- Install a minimum 4-inch diameter combination air and vacuum valve at STA. 9+29 on the ICF (see Figure 1 of this report for location), if not already installed at this location.

A vacuum relief-air inlet valve in combination with a small orifice diameter air release valve (e.g., APCO S-1500C, or equivalent) or a single body valve (e.g., Vent-O-Mat) are examples of valves that control the venting of the air from the system upon re-pressurization. Alternatively, a combination air valve with a slow closing surge check feature could be used.

Each vacuum relief valve should be duplicated to provide redundancy in case of valve failure or removal for servicing. A regular vacuum relief valve maintenance program should be put in place to ensure that the valves are always in good working order.

The above recommended surge protection will protect the pipelines following power failure to the booster pump stations if the diameter of the pipeline from the desalination plant to OC-44 is either 42 inches or 48 inches.

The pumps at BPS#1 should be ramped up to full speed in 45 seconds or longer and each subsequent pump start should be lagged by at least 90 seconds. In addition, the pumps at BPS#2 and BPS#3 should be ramped up to full speed in 30 seconds or longer and each subsequent pump start should be lagged by at least 90 seconds.

It is important to note that this pressure surge analysis was conducted for the system as described at a preliminary planning stage. The results of the analysis (both power failure and startup) and the recommendations derived from the analysis should be checked once more detailed planning and design of the proposed pump stations and pipeline have been completed.

Necessary Hydraulic Modifications to the Existing Distribution System

To facilitate the delivery of desalination plant product water via the proposed booster pump stations and existing pipelines, Flow Science believes that the following hydraulic modifications to the distribution system, which are unrelated to surge protection, are necessary:

- Install a 42-inch diameter bypass with a hydraulically operated isolation valve (e.g., ball, plug or cone valve) around the closed pressure control valves at STA. 254+00 on the OC-44 transmission main. The pressure control valves at this location reduce the pressure to an HGL elevation less than 438 ft when the Diemer WTP is supplying flow to the OC-44 transmission main (i.e., under the existing non-pumping mode), but will be closed when the booster pump stations are operating.

- Lockout the pressure relief valve at STA. 1090+95 on EOCF#2 when BPS#2 is in operation so that the pressure relief valve will not open when the HGL elevation exceeds the set point elevation of 485 ft at this location. Note that this existing pressure relief valve is required when the Diemer WTP is supplying flow to EOCF#2 between Coastal Junction and the ICF (i.e., under the existing non-pumping mode).

- Install a pressure control valve with a downstream set point less than 480 ft on the EOCF#2 between BPS#2 and the ICF (i.e., just upstream of STA. 1237+79 on EOCF#2). This valve will prevent the over-pressurization of the ICF (i.e., it will prevent the HGL elevation in the ICF from exceeding 485 ft) and air gap spillage at the San Joaquin Reservoir when BPS#2 is in operation.

Poseidon Resources Huntington Beach Seawater Desalination Plant

Figure 1 – Pipe System Schematic

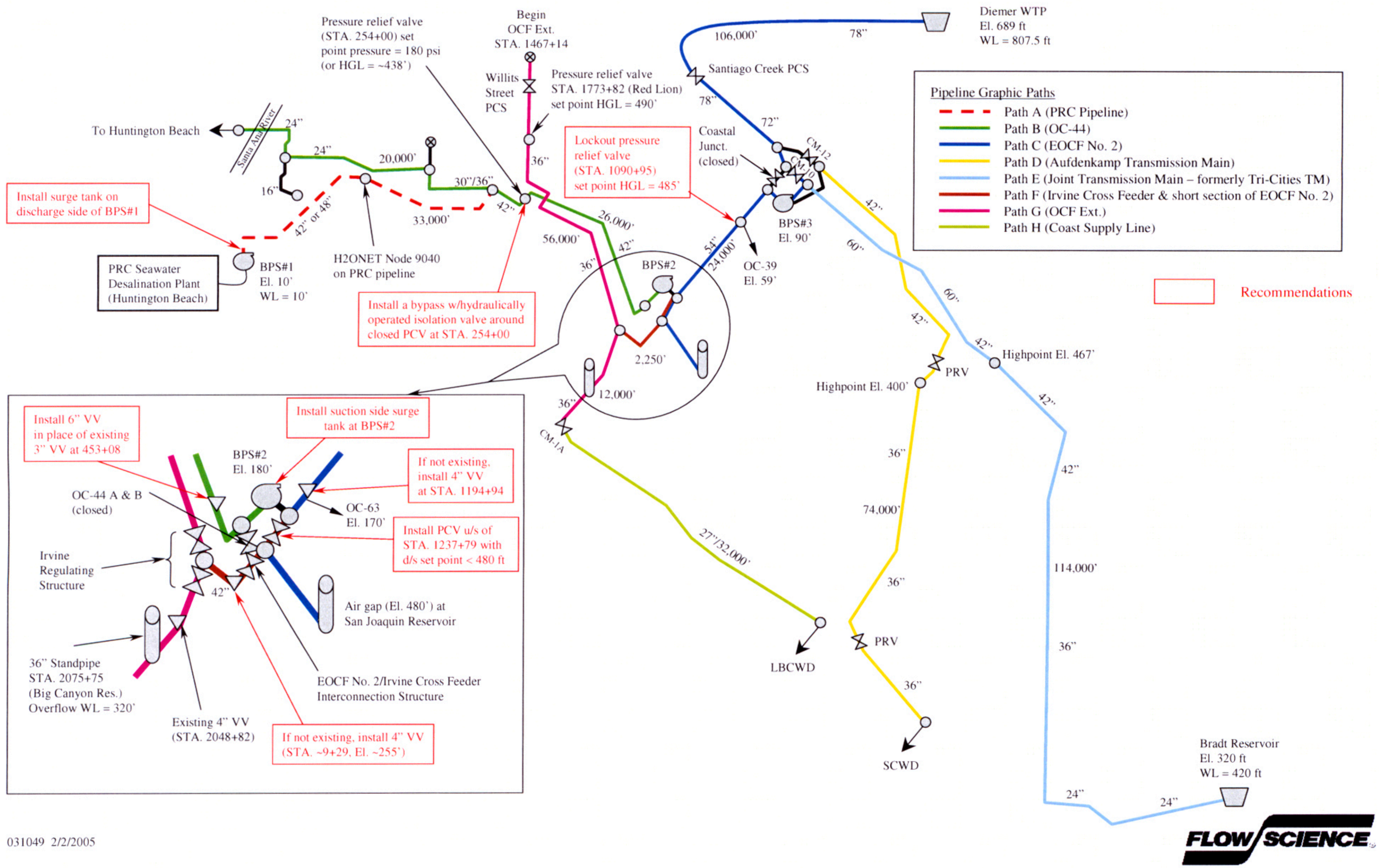

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Figure 2 - HGL's in Path A after loss of power to pump stations without surge protection

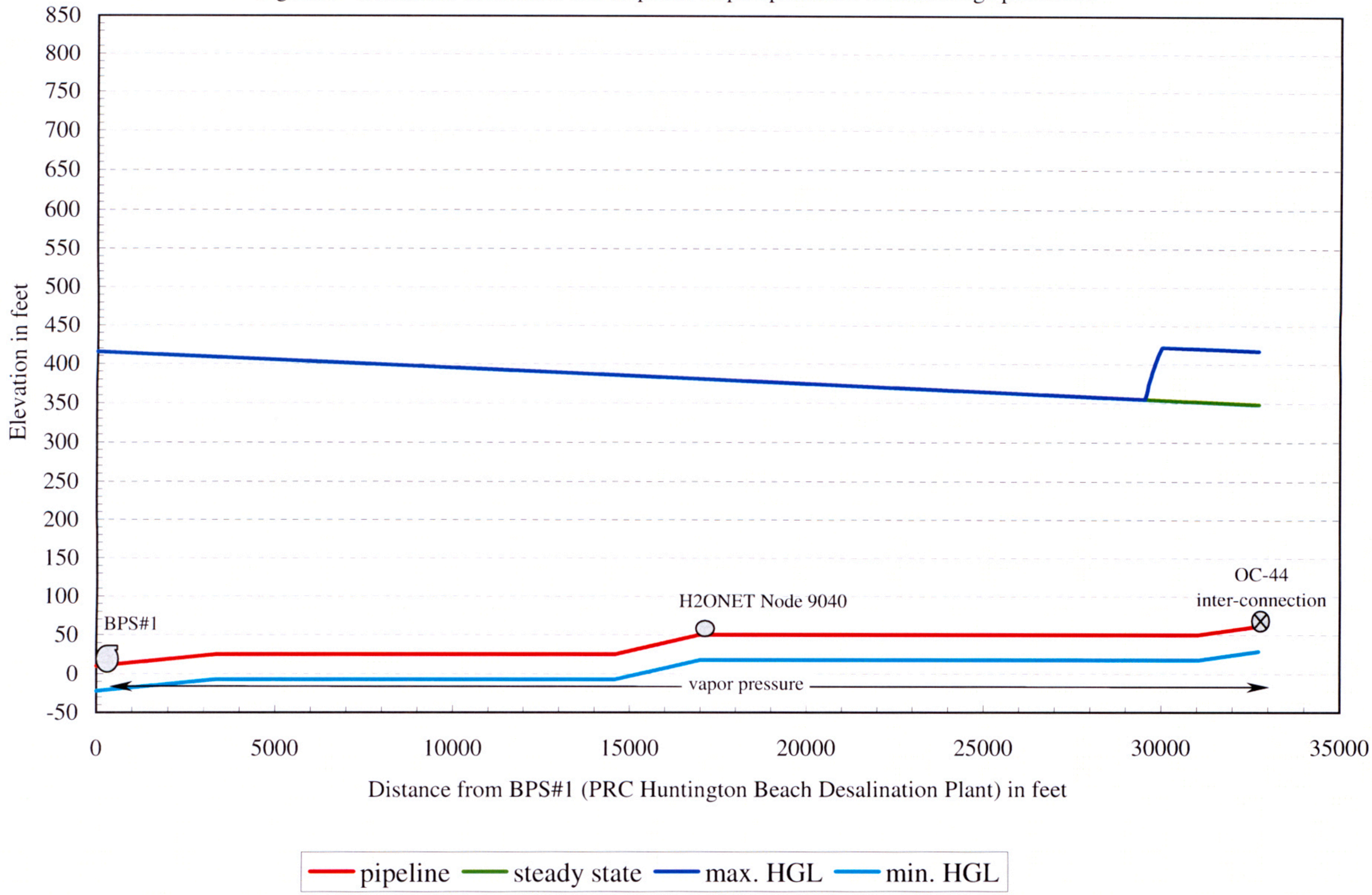

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Figure 3 - Pressure heads after loss of power to pump stations without surge protection

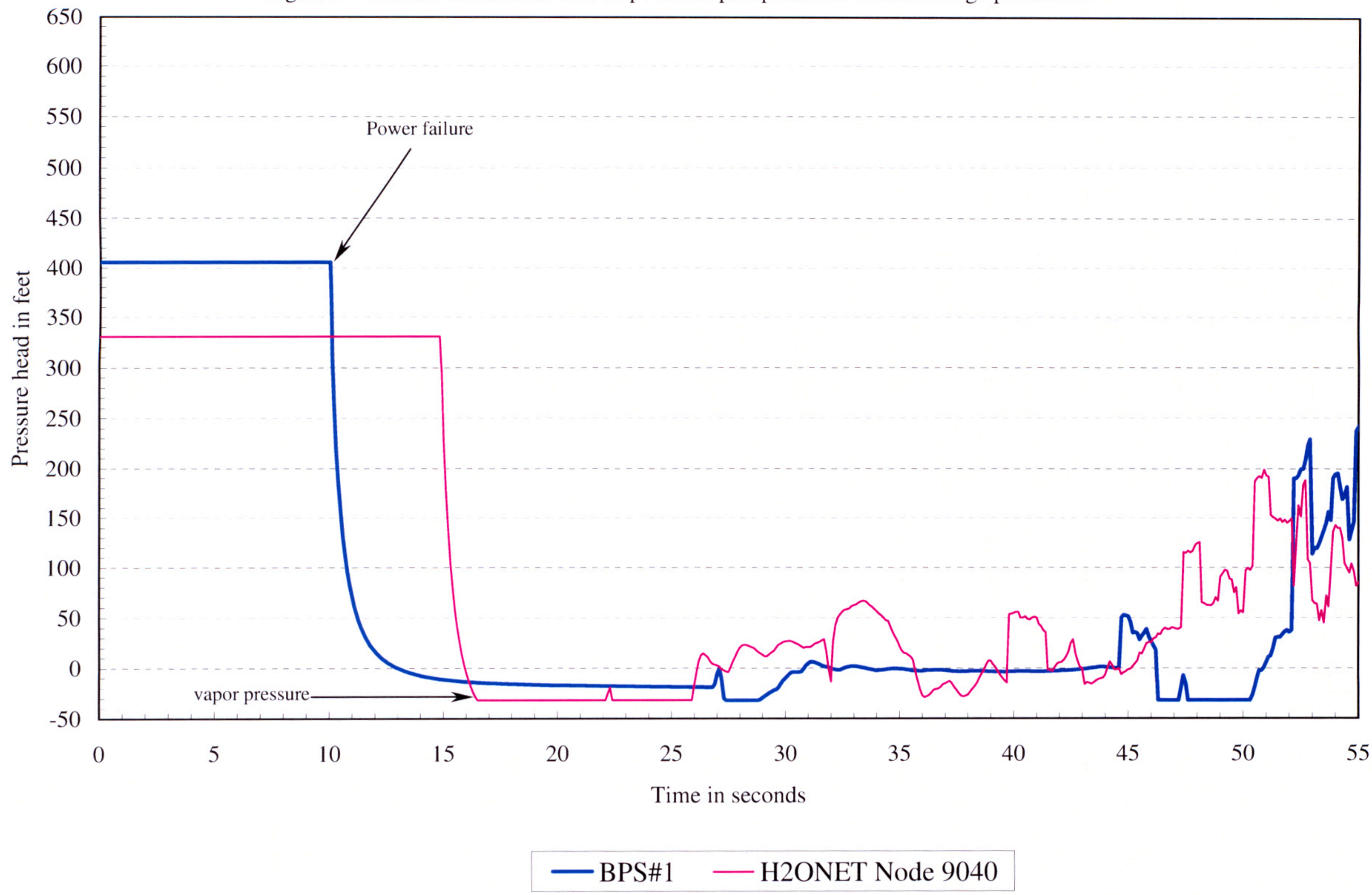

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Figure 4 - HGL's in Path B after loss of power to pump stations without surge protection

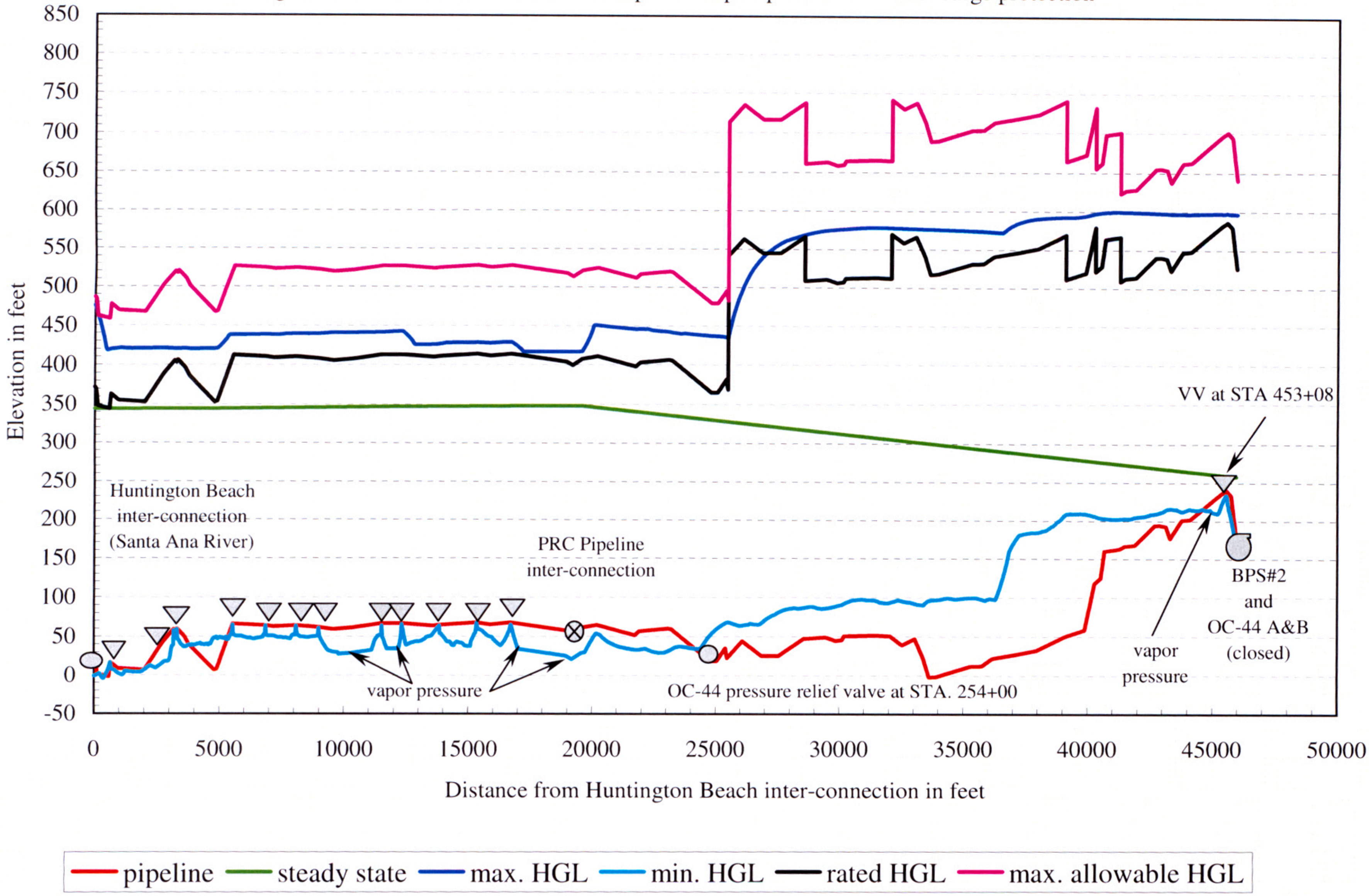

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Figure 5 - Pressure heads after loss of power to pump stations without surge protection

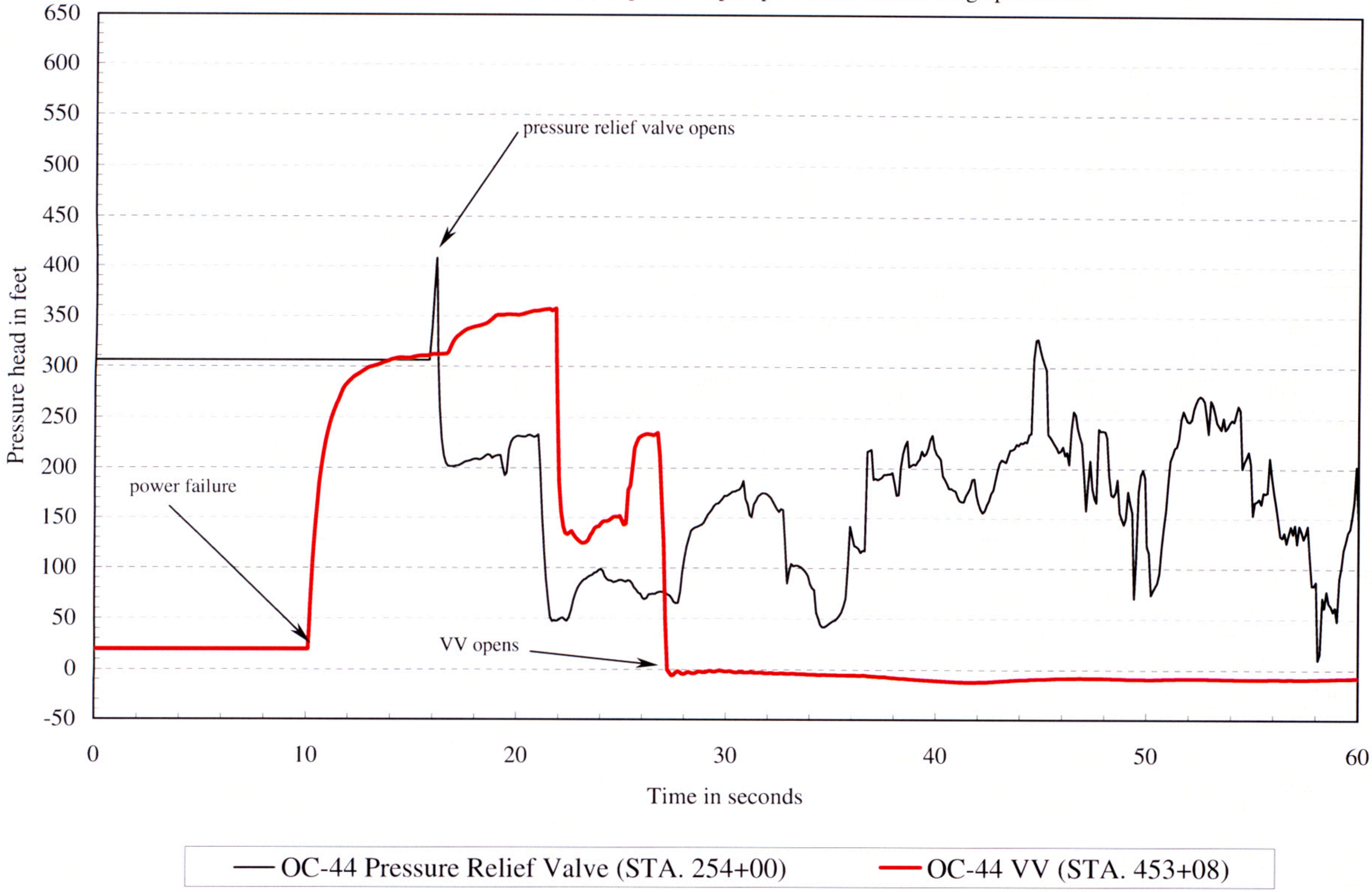

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Figure 6 - HGL's in Path C after loss of power to pump stations without surge protection

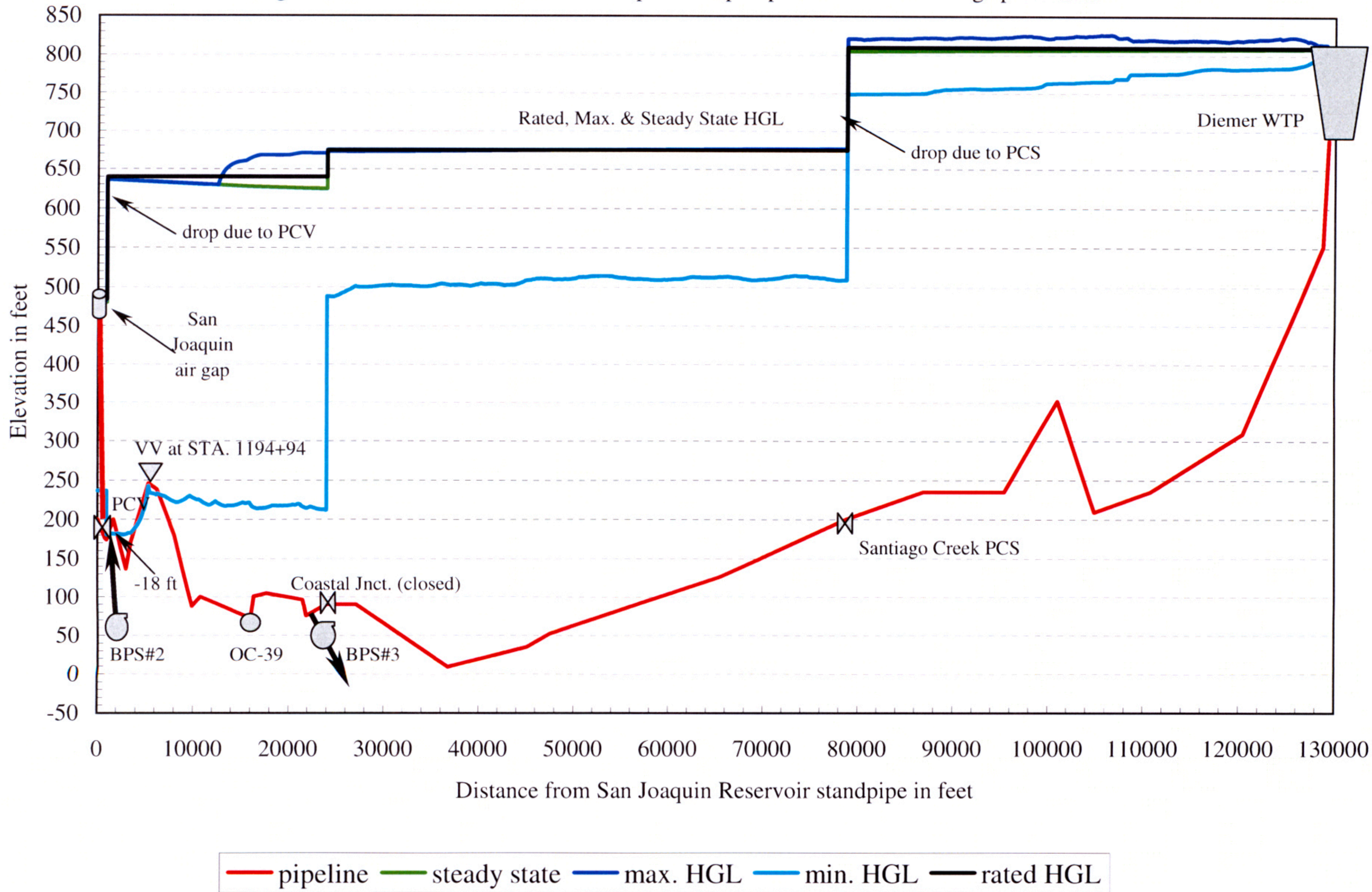

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Figure 7 - Pressure heads after loss of power to pump stations without surge protection

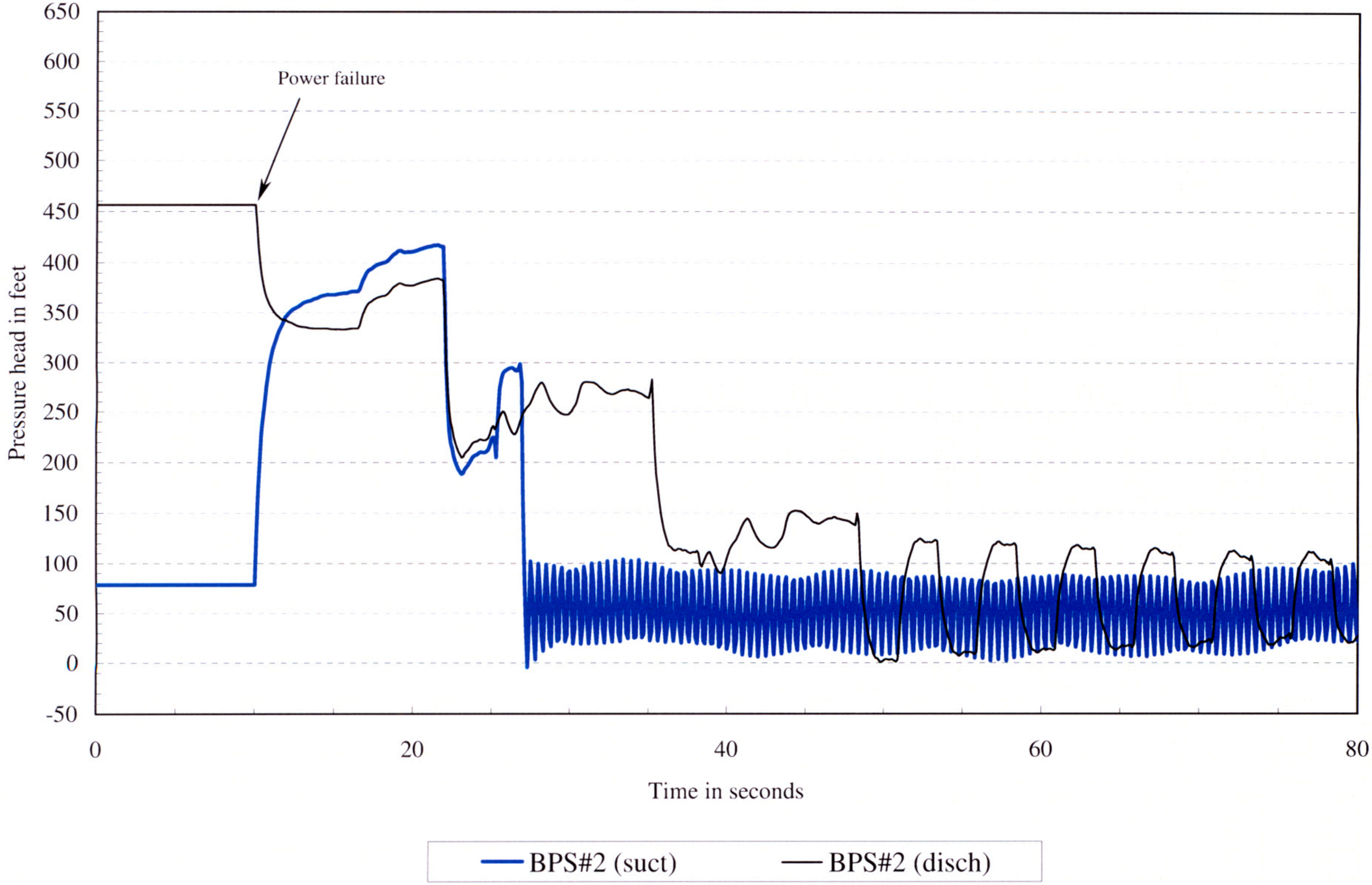

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Figure 8 - Pressure heads after loss of power to pump stations without surge protection

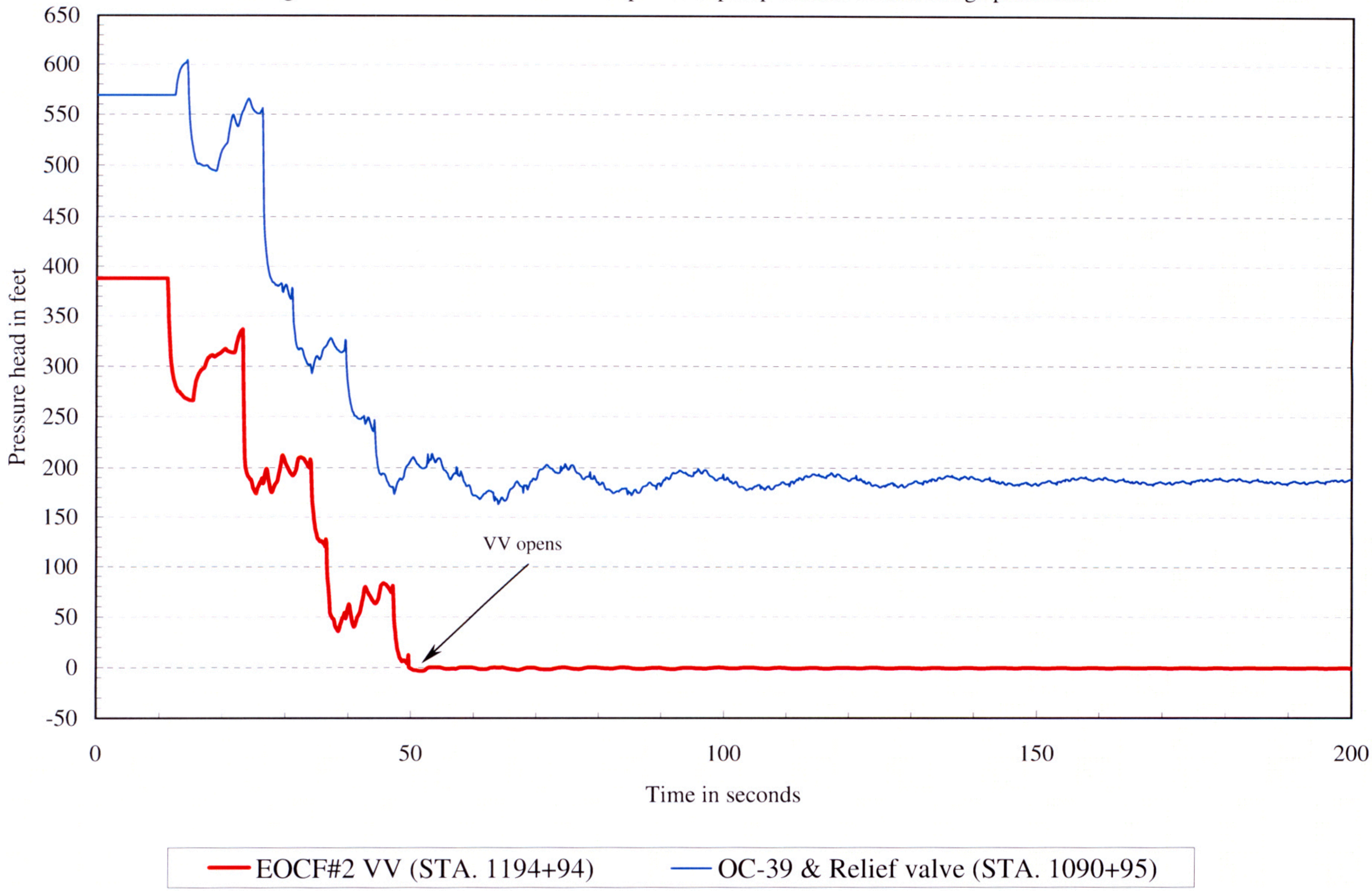

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Figure 9 - HGL's in Path D after loss of power to pump stations without surge protection

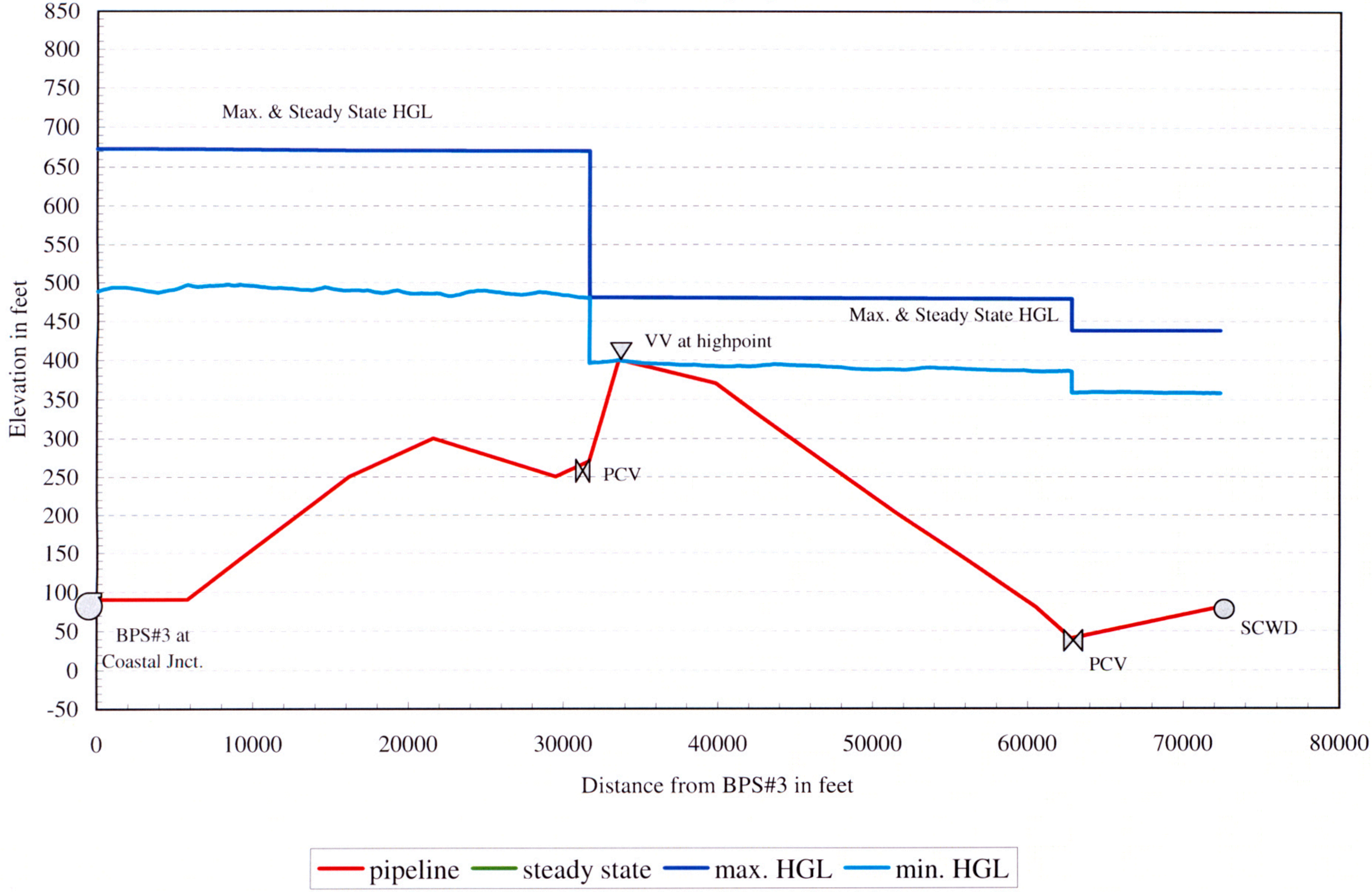

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Figure 10 - HGL's in Path E after loss of power to pump stations without surge protection

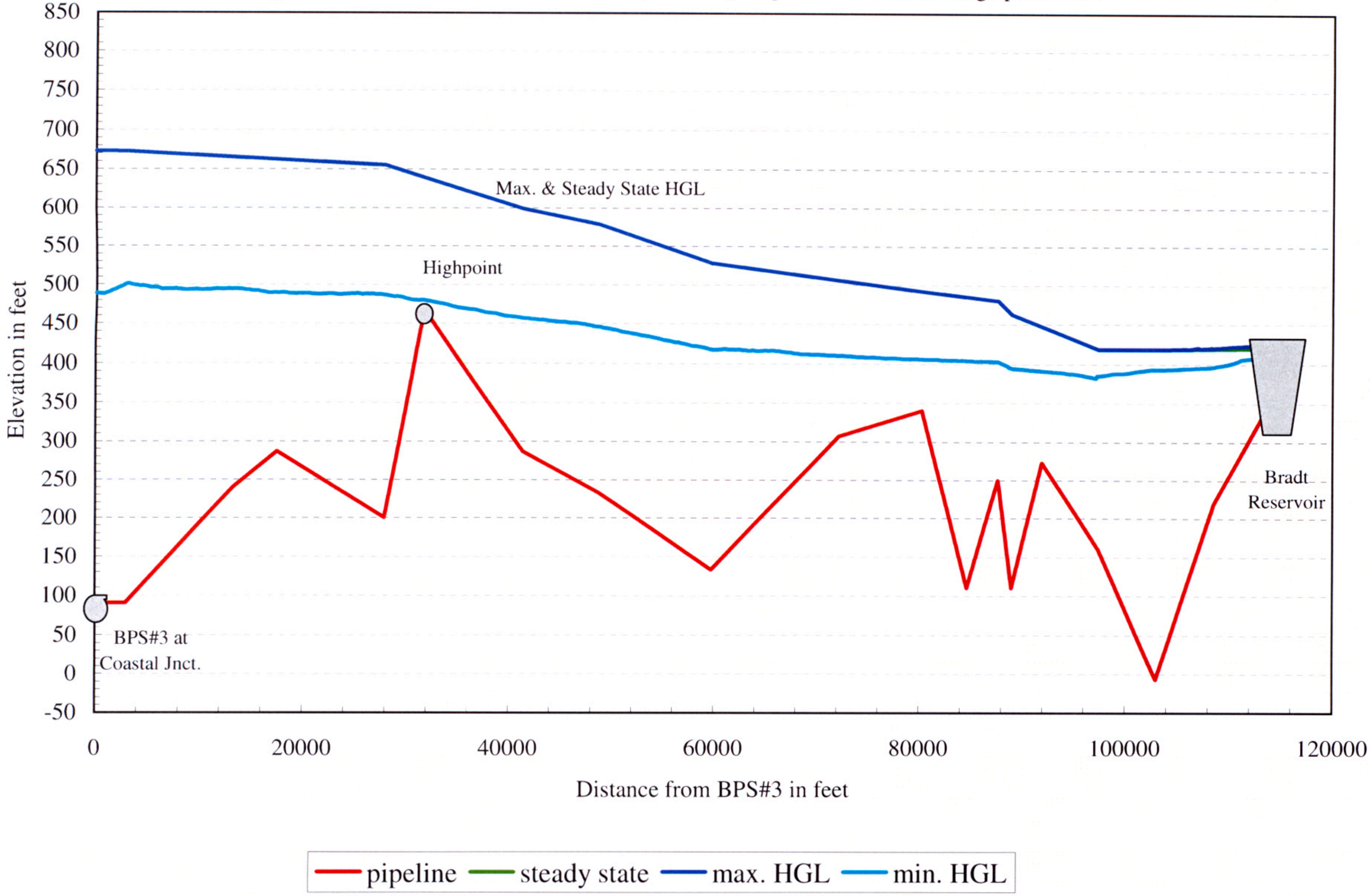

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Figure 11 - Pressure heads after loss of power to pump stations without surge protection

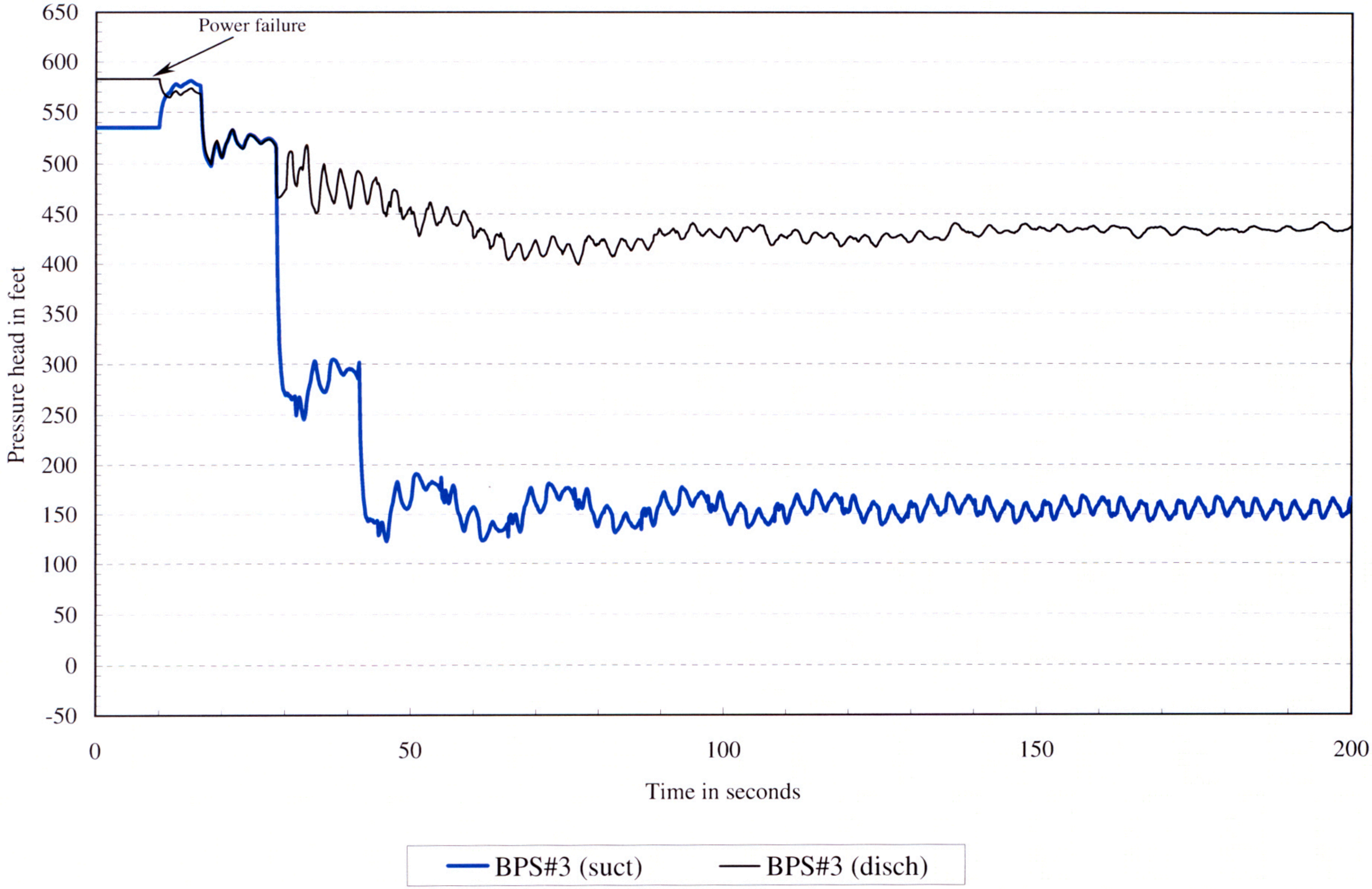

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Figure 12 - Pressure heads after loss of power to pump stations without surge protection

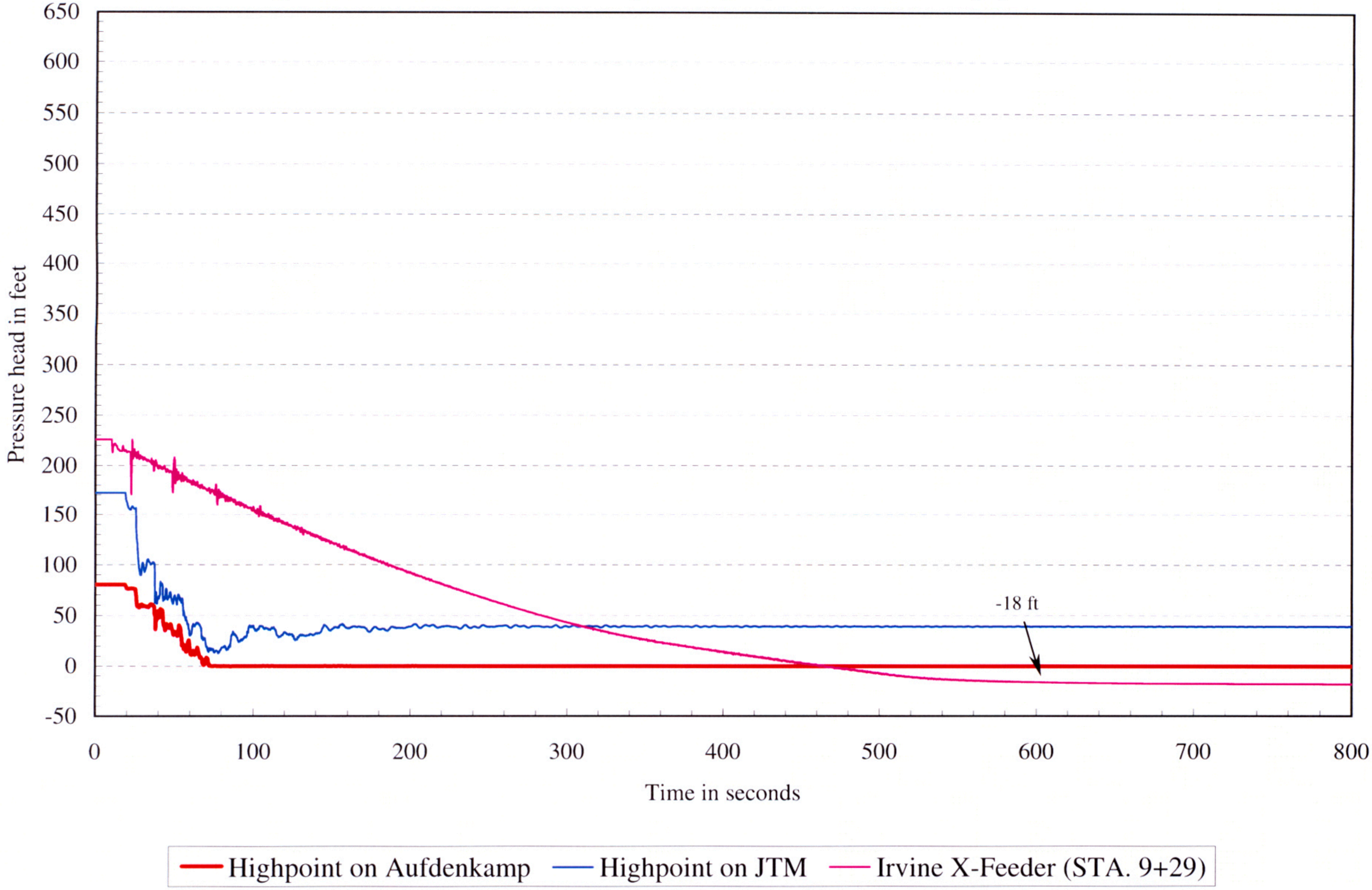

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Figure 13 - HGL's in Path F after loss of power to pump stations without surge protection

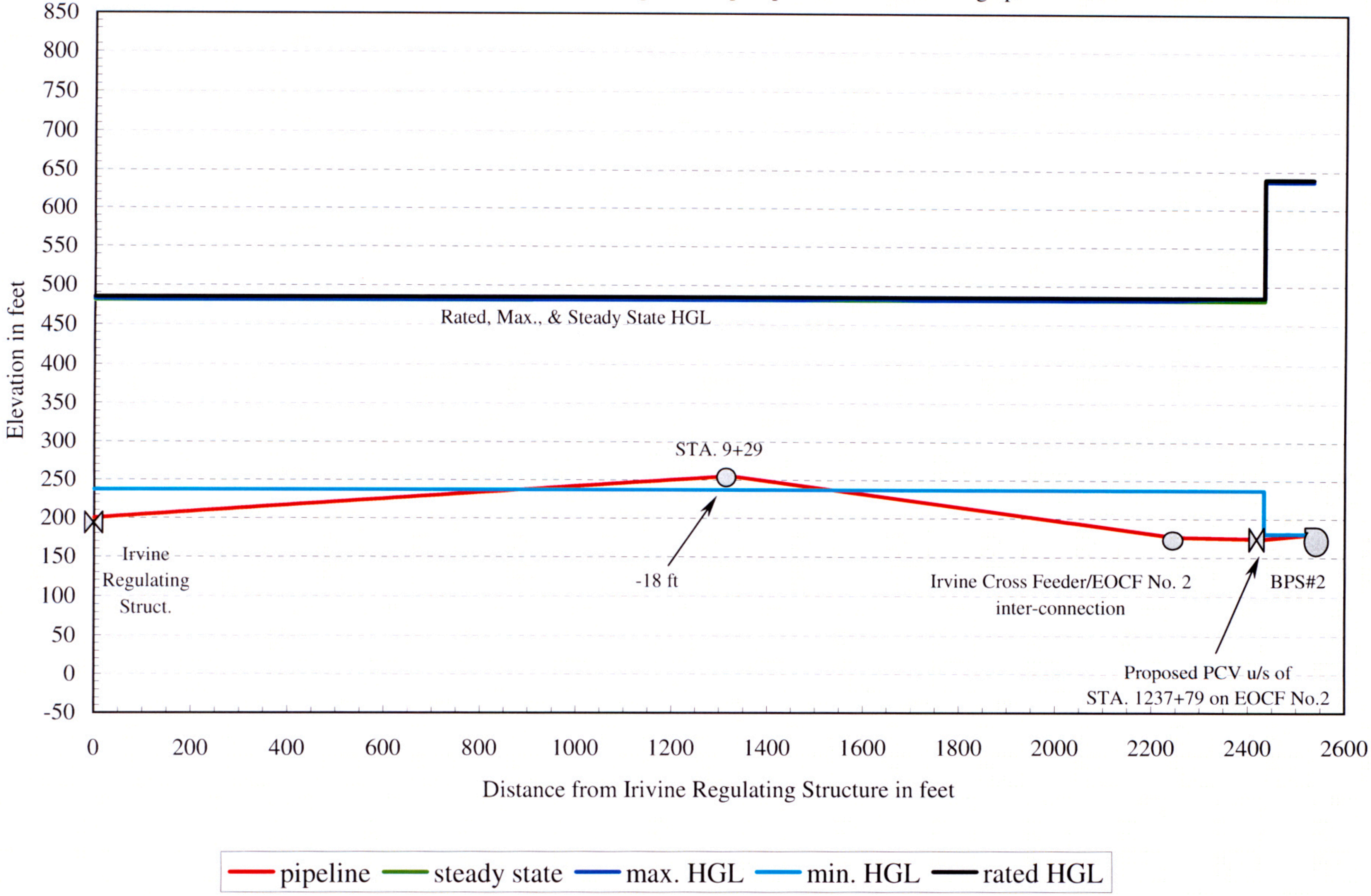

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Figure 14 - HGL's in Path G after loss of power to pump stations without surge protection

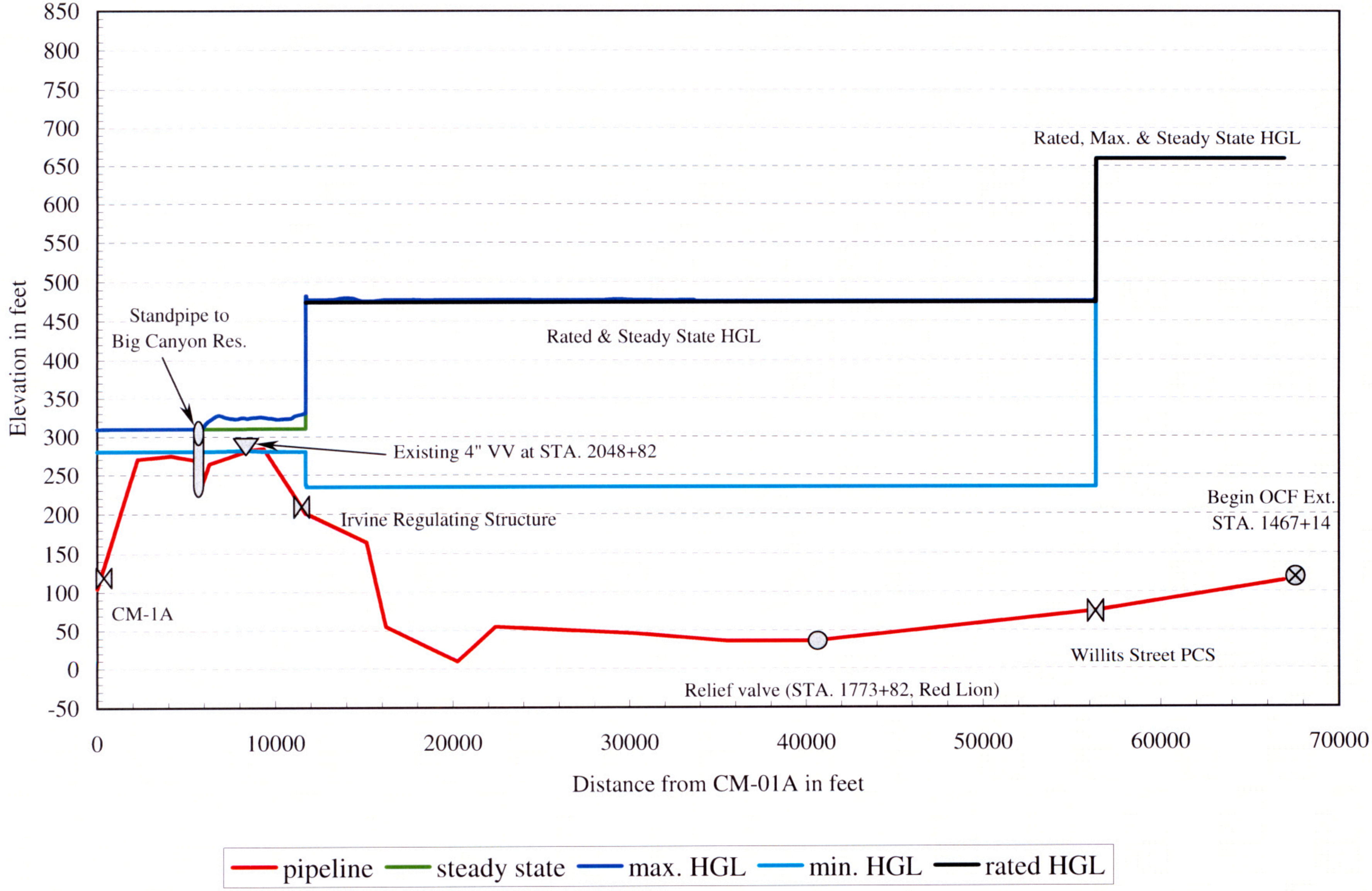

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Figure 15 - HGL's in Path H after loss of power to pump stations without surge protection

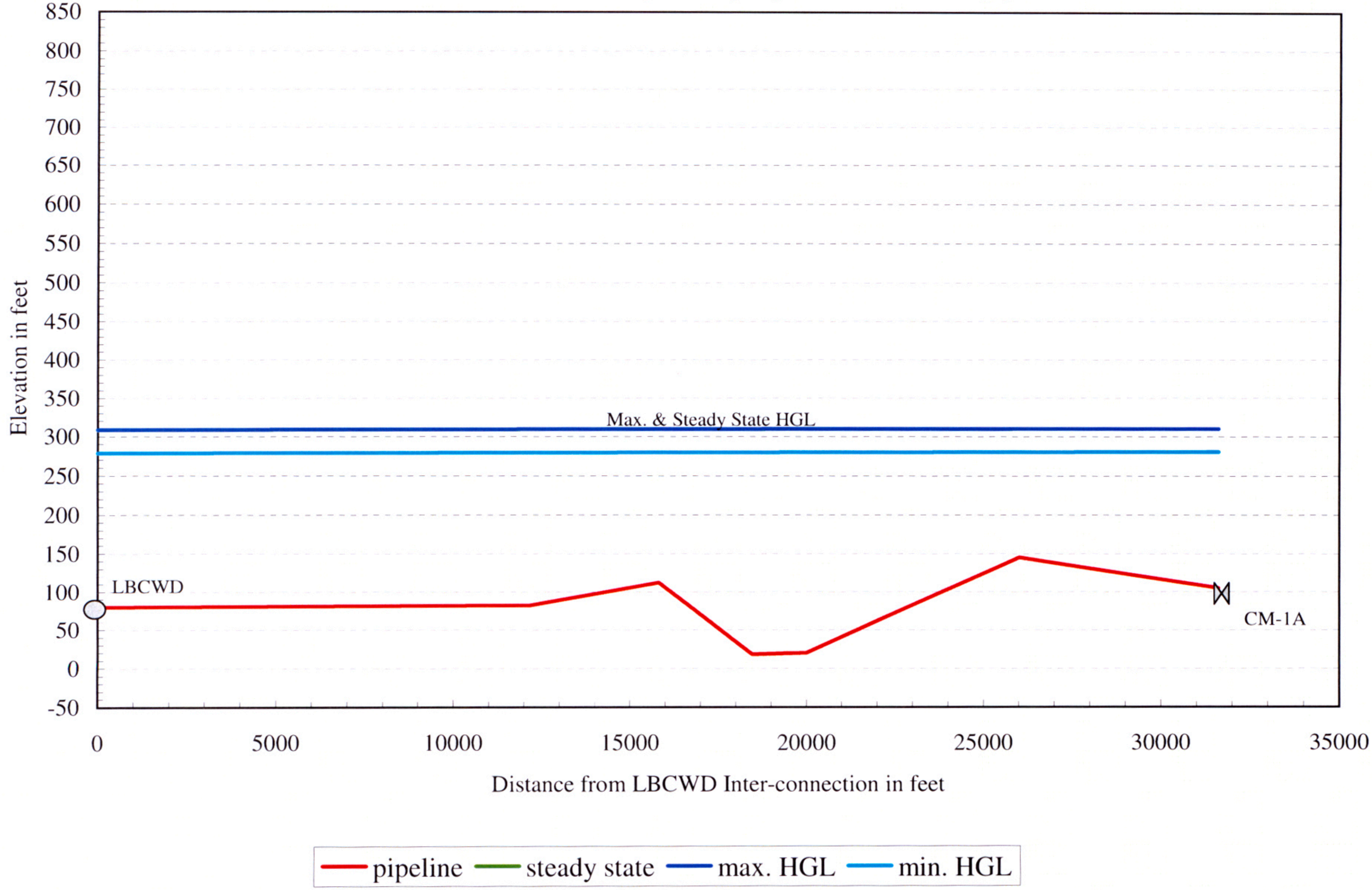

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Figure 16 - Pressure heads after loss of power to pump stations without surge protection

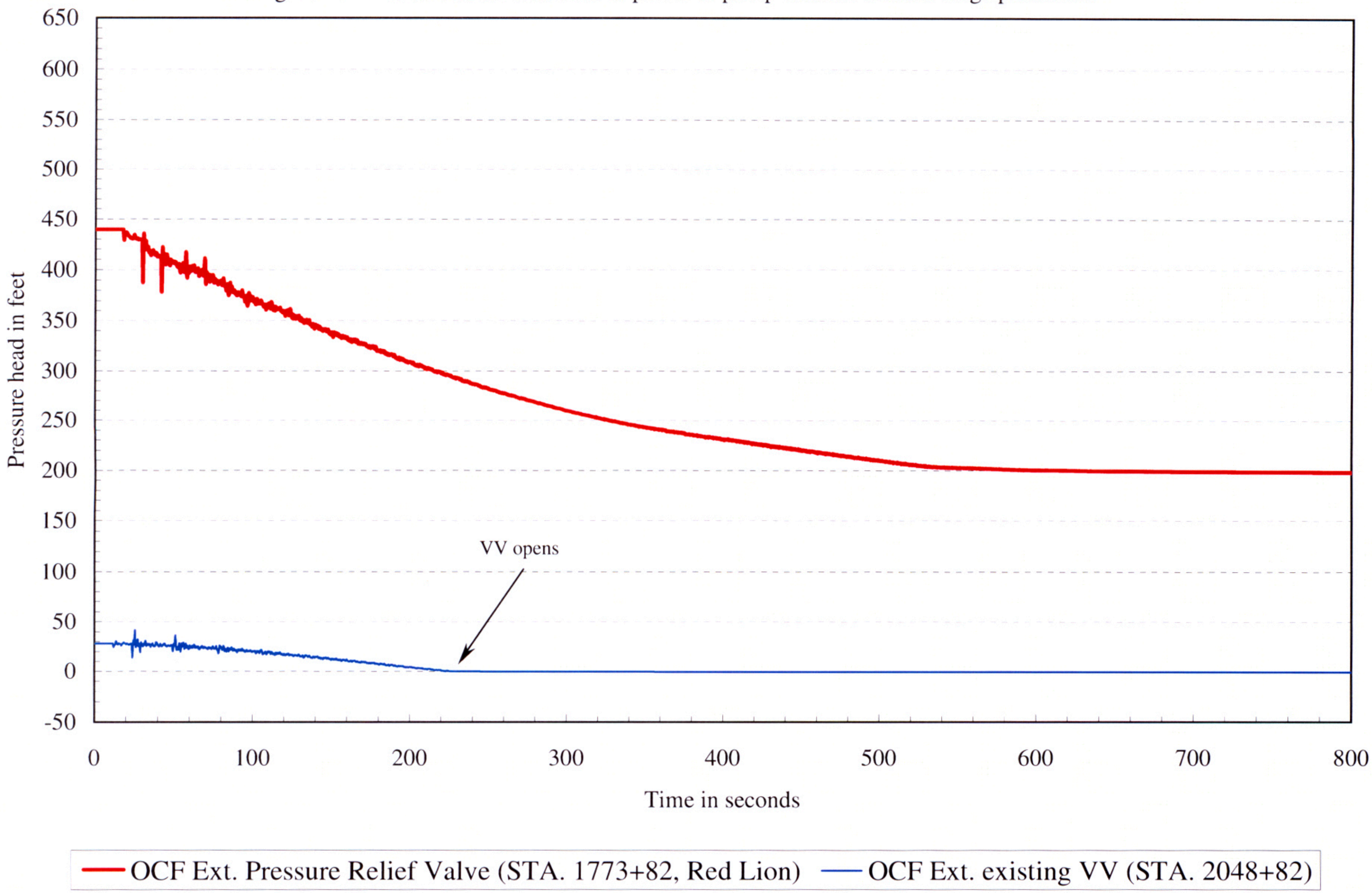

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Figure 17 - HGL's in Path A after loss of power to pump stations with surge protection

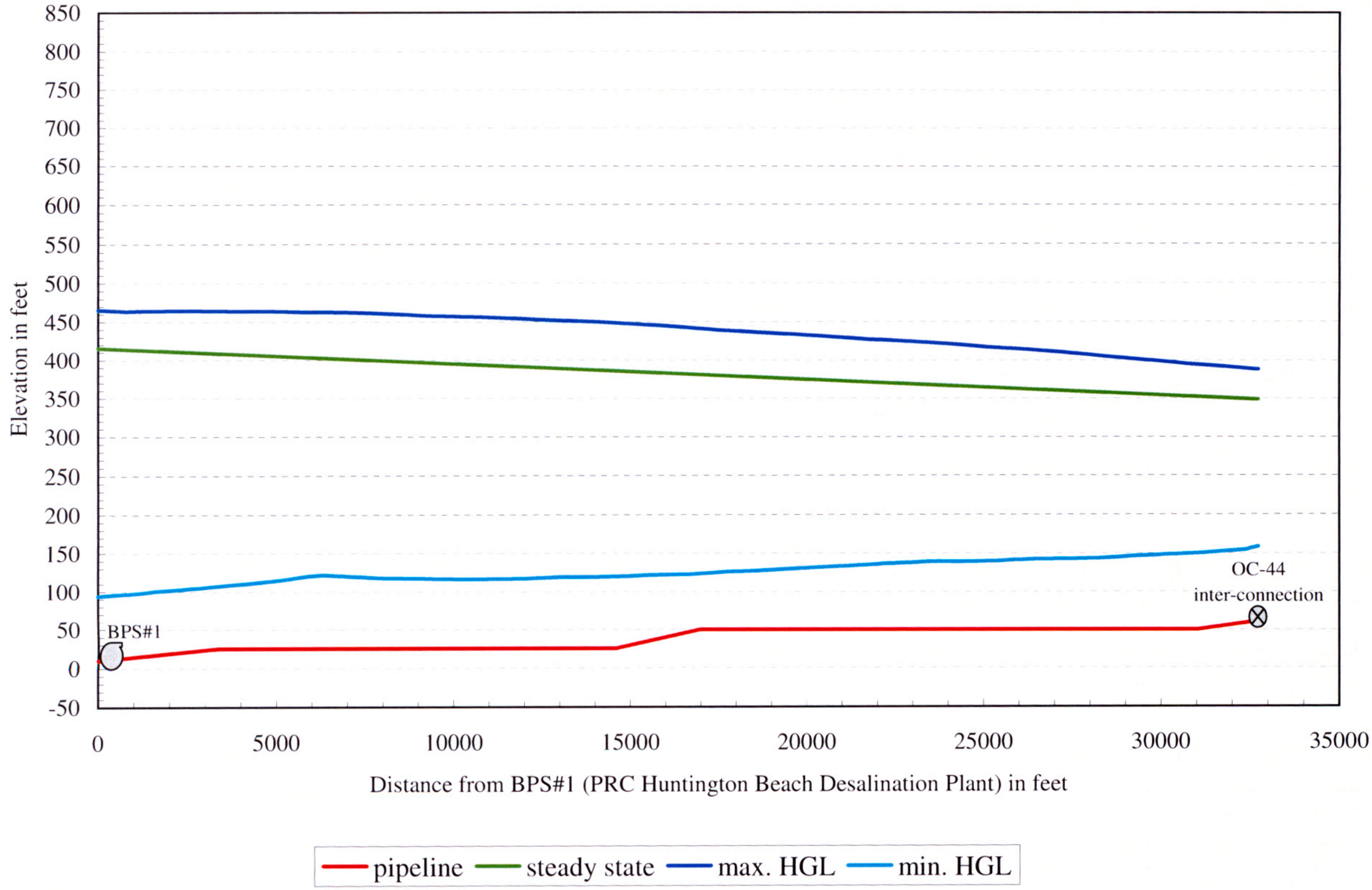

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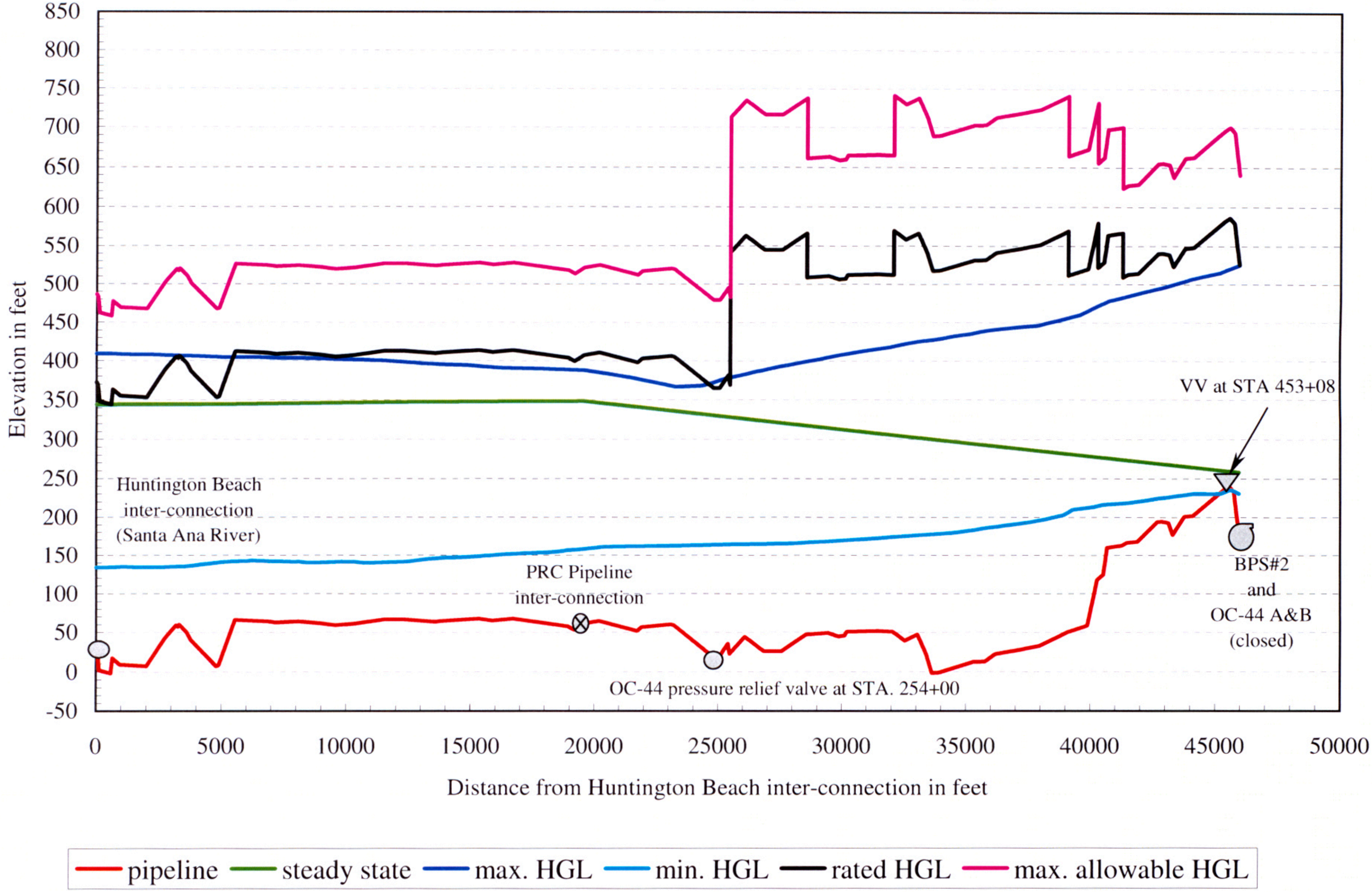
Figure 18 - HGL's in Path B after loss of power to pump stations with surge protection



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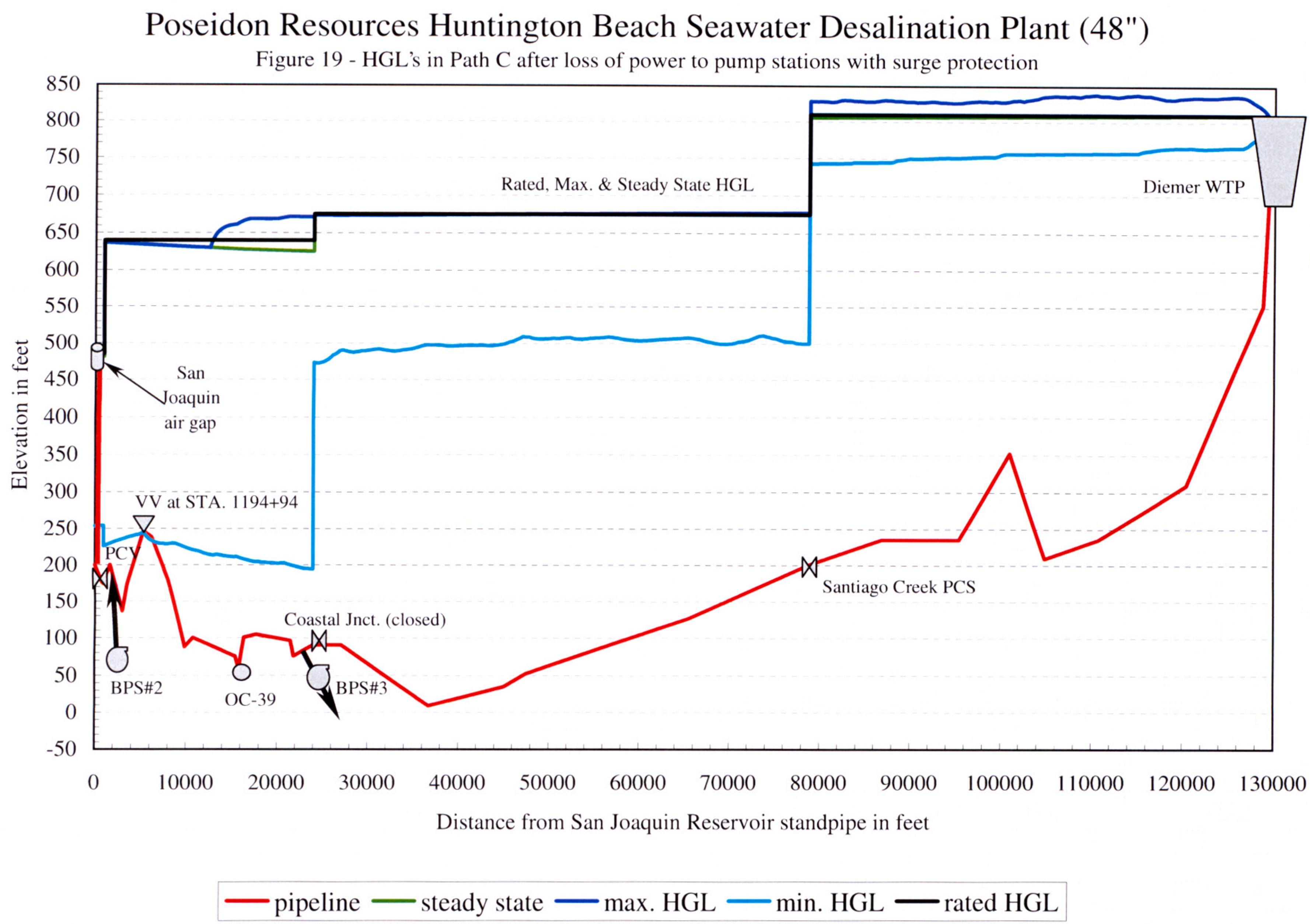

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Figure 19 - HGL's in Path C after loss of power to pump stations with surge protection
Elevation in feet
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
Distance from San Joaquin Reservoir standpipe in feet
Rated, Max. & Steady State HGL
Diemer WTP
San Joaquin air gap
VV at STA. 1194+94
PCV
BPS#2
OC-39
Coastal Jnct. (closed)
BPS#3
Santiago Creek PCS
pipeline
steady state
max. HGL
min. HGL
rated HGL

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Figure 20 - HGL's in Path D after loss of power to pump stations with surge protection

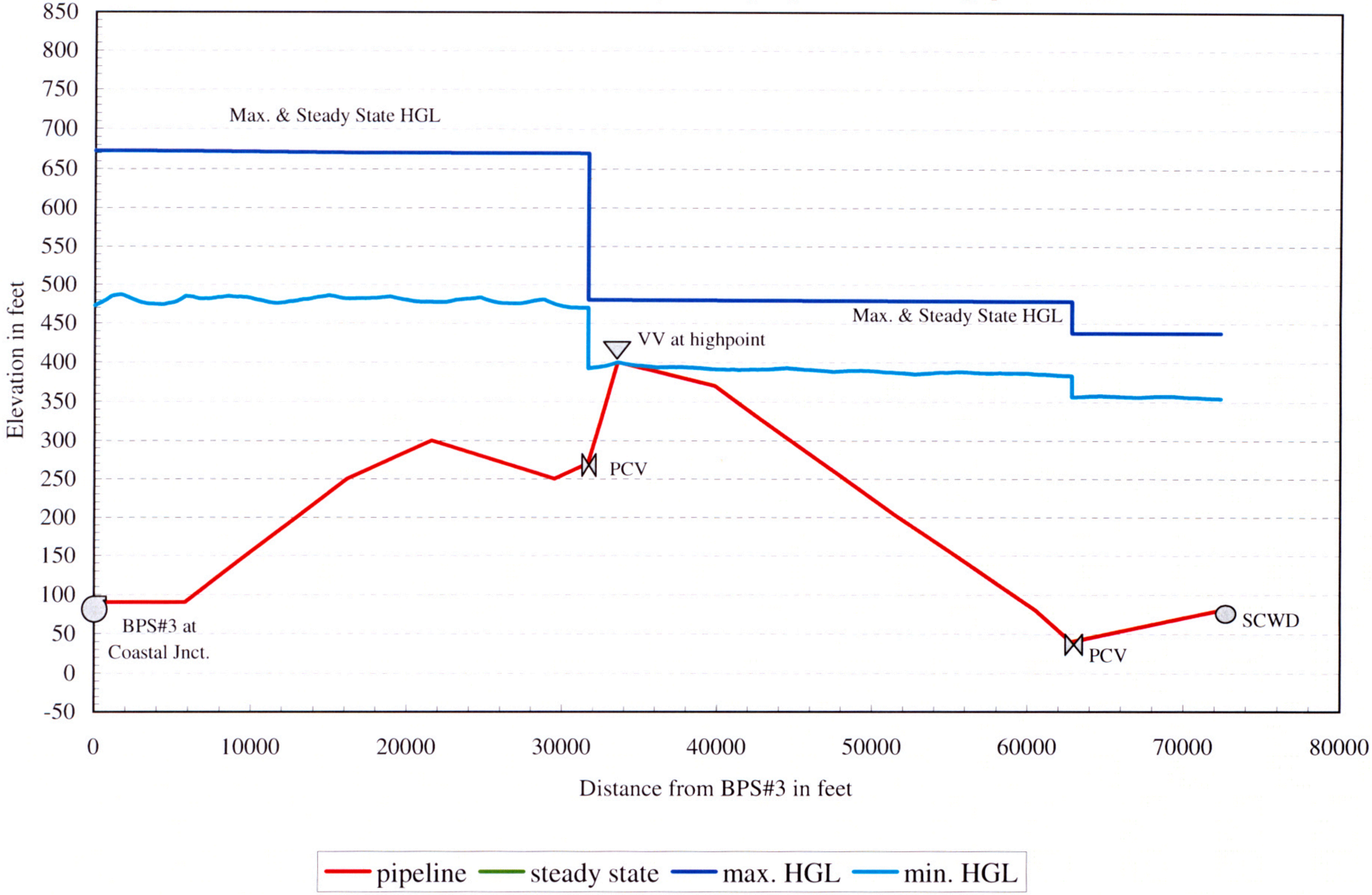

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Figure 21 - HGL's in Path E after loss of power to pump stations with surge protection

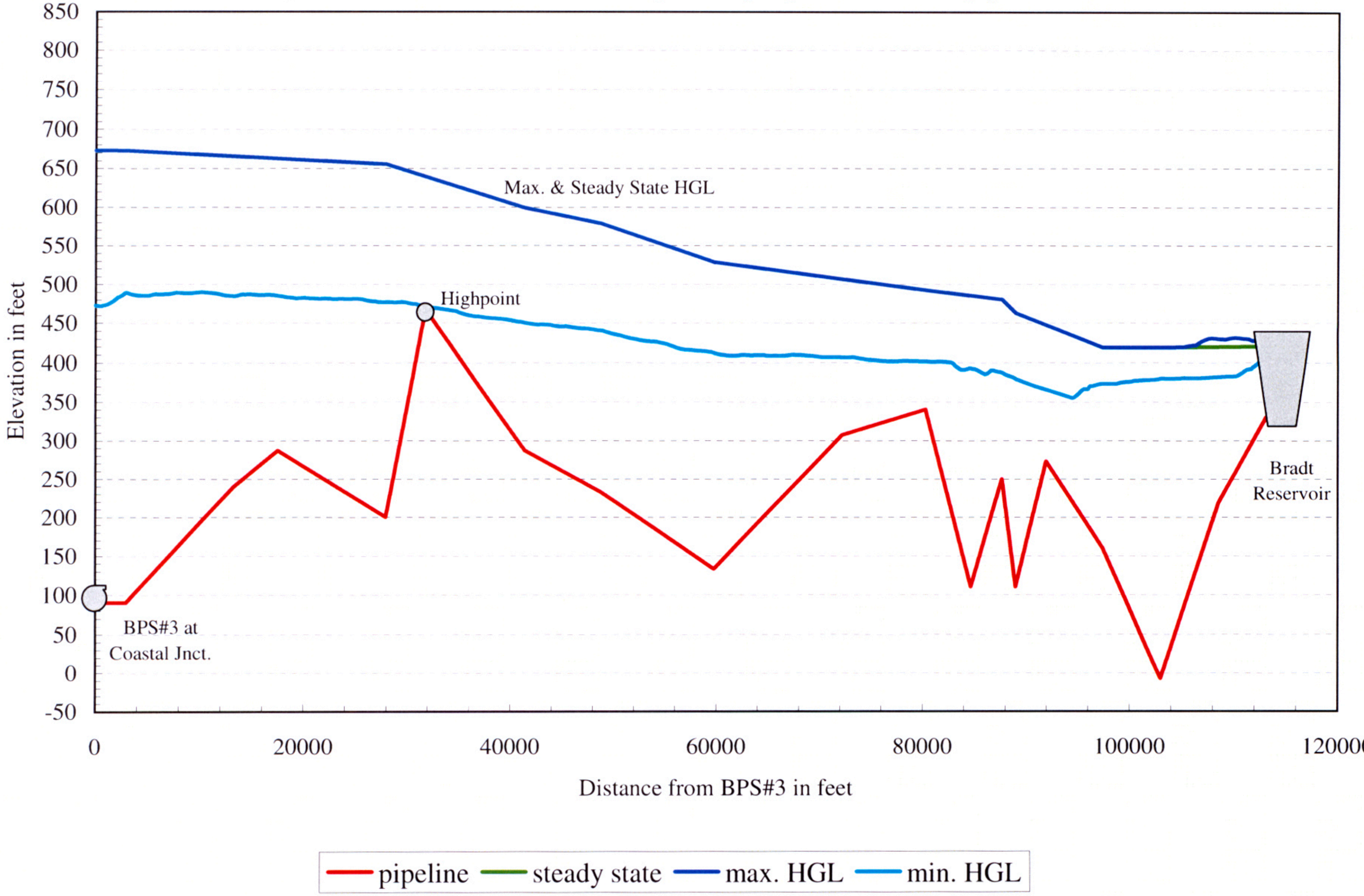

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Figure 22 - HGL's in Path F after loss of power to pump stations with surge protection

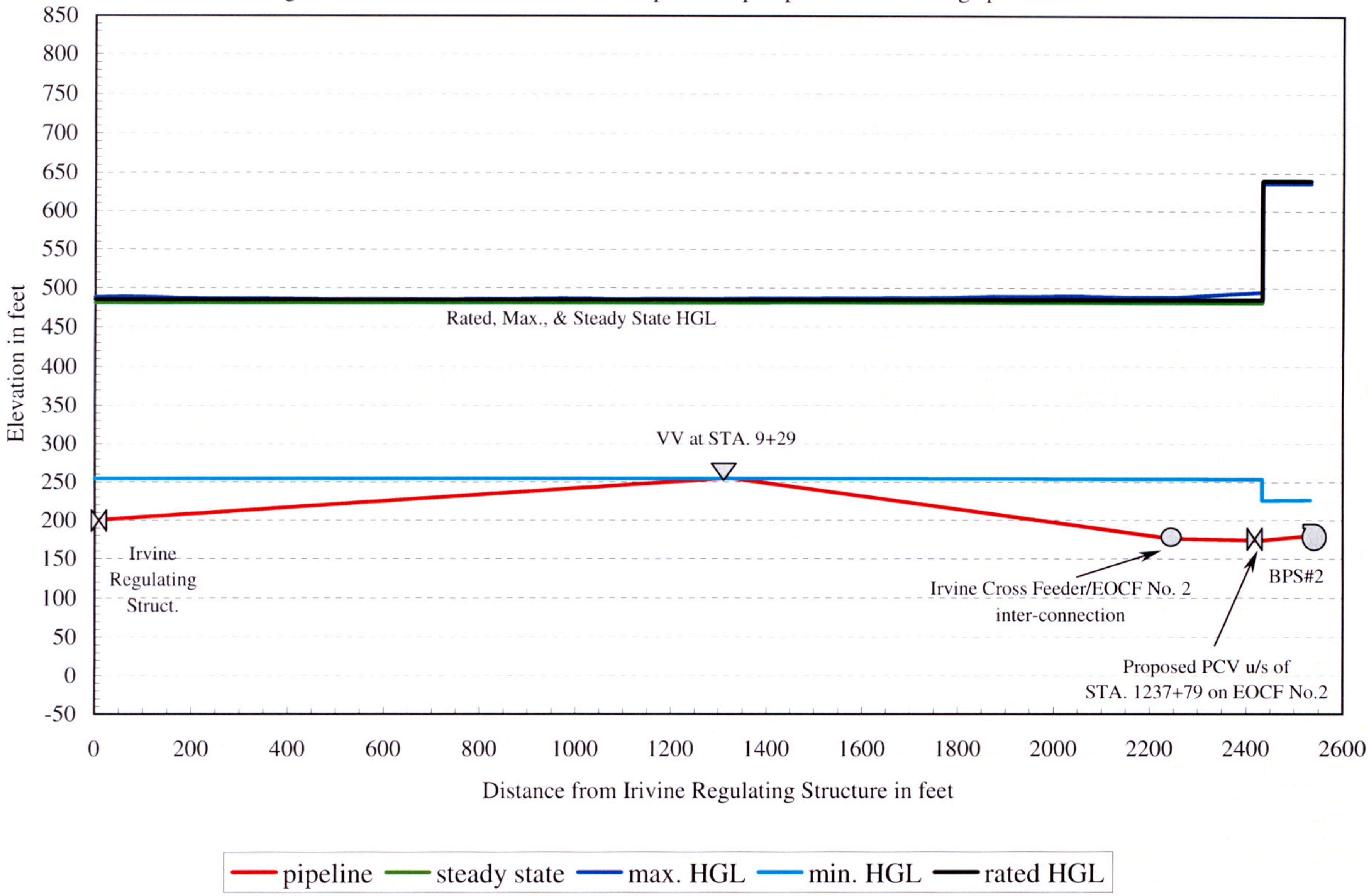

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Figure 23 - HGL's in Path G after loss of power to pump stations with surge protection

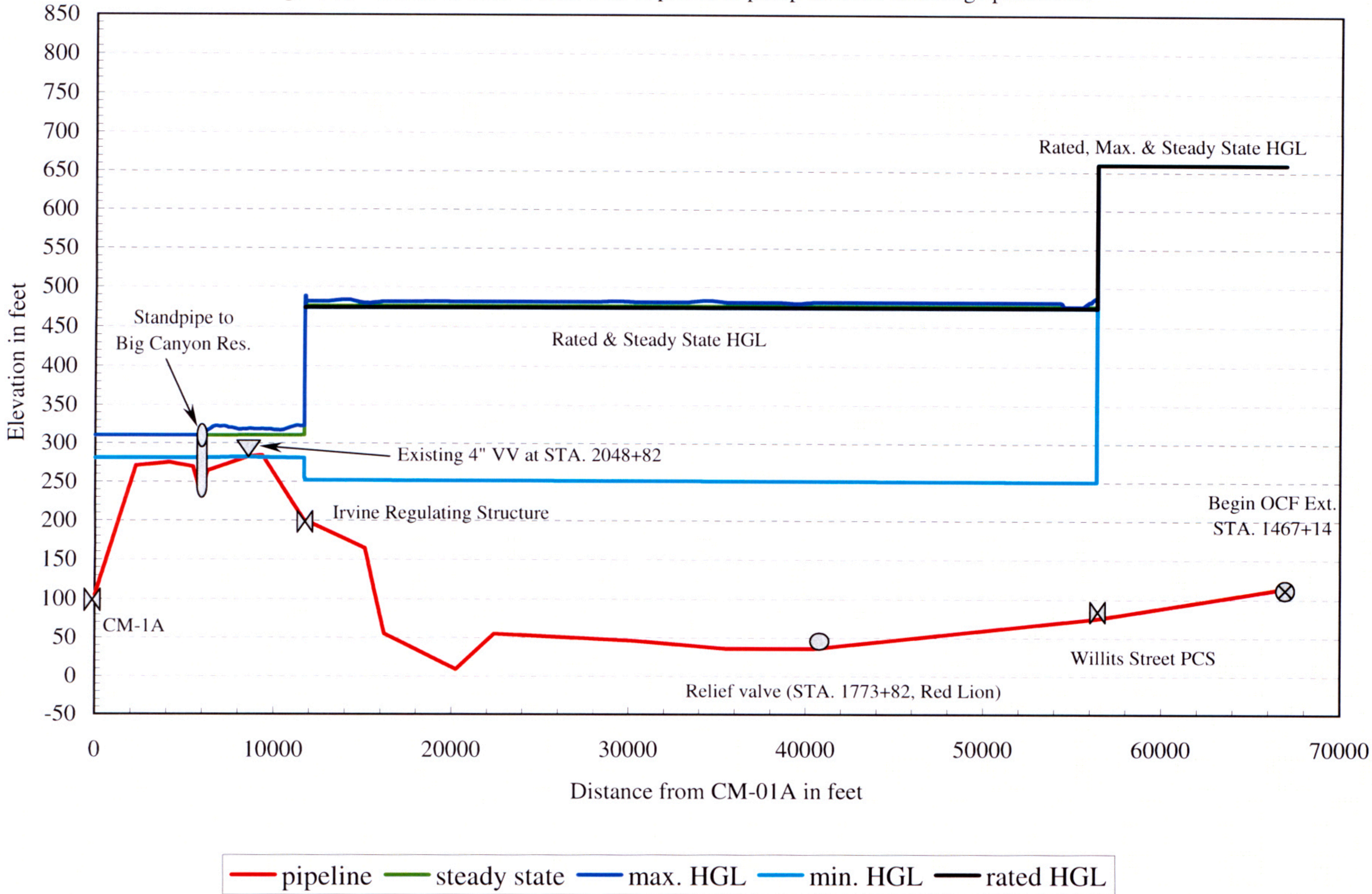

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Figure 24 - HGL's in Path H after loss of power to pump stations with surge protection

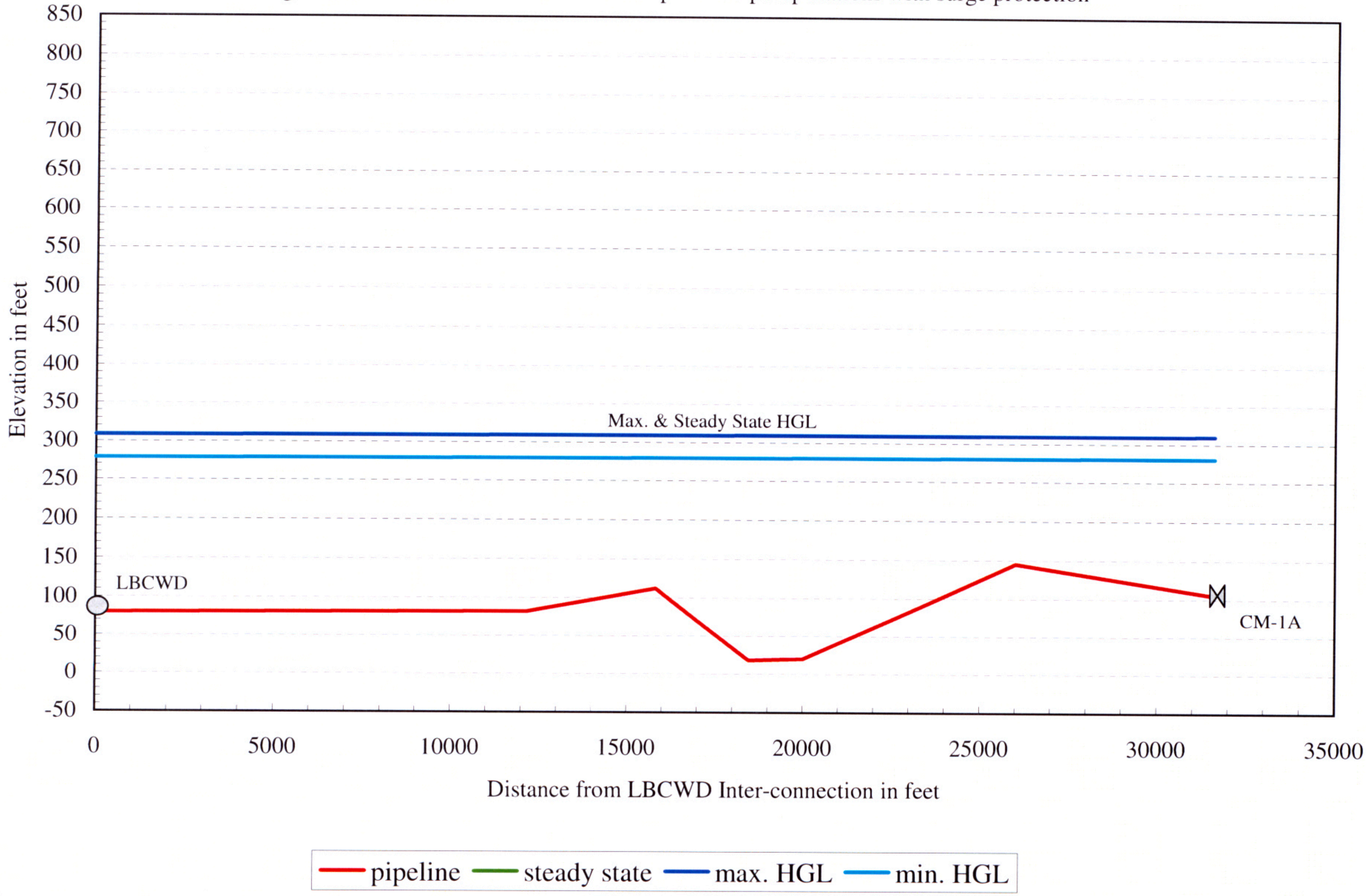

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Figure 25 - Pressure heads after loss of power to pump stations with surge protection

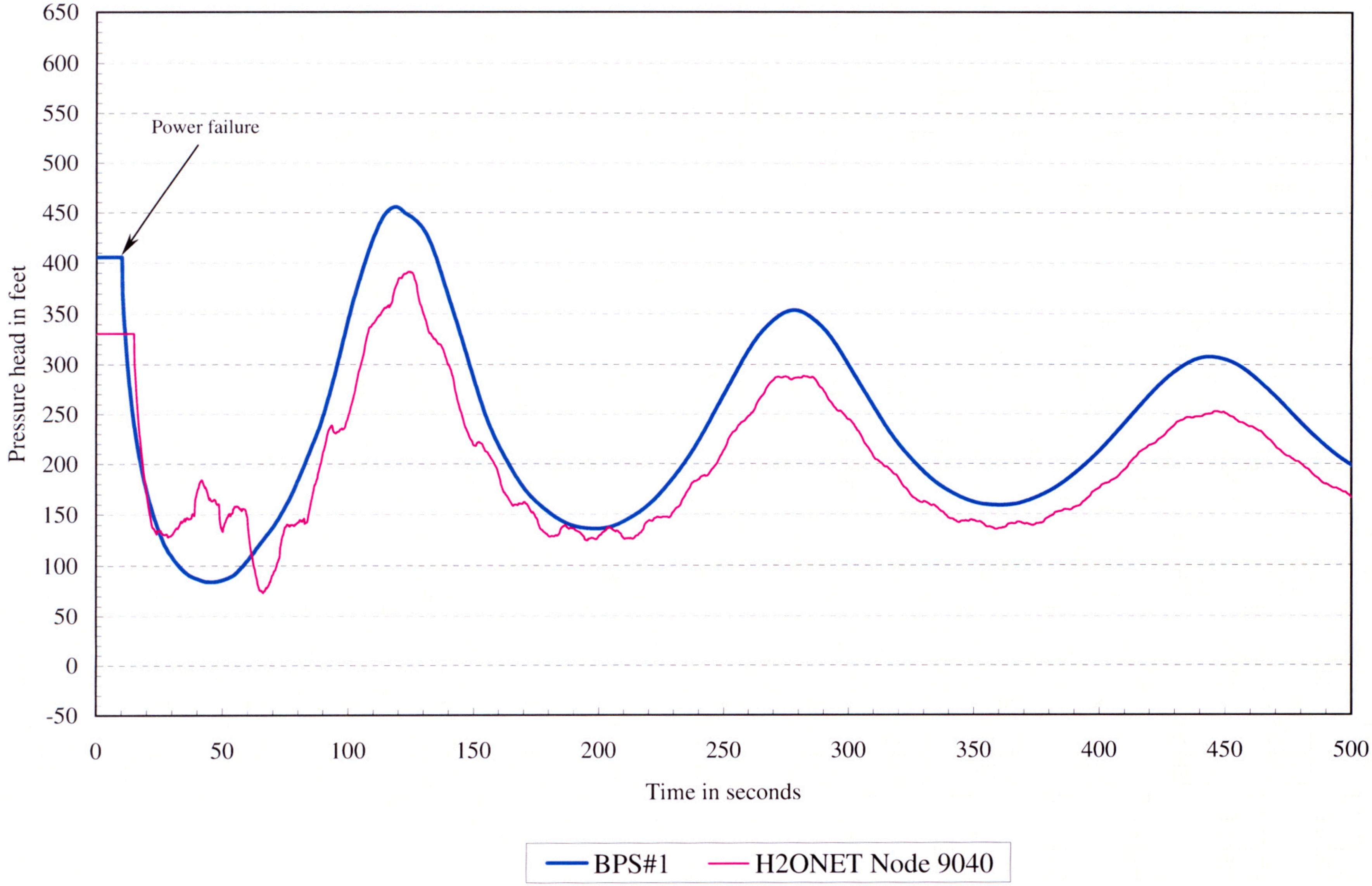

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Figure 26 -Pressure heads after loss of power to pump stations with surge protection

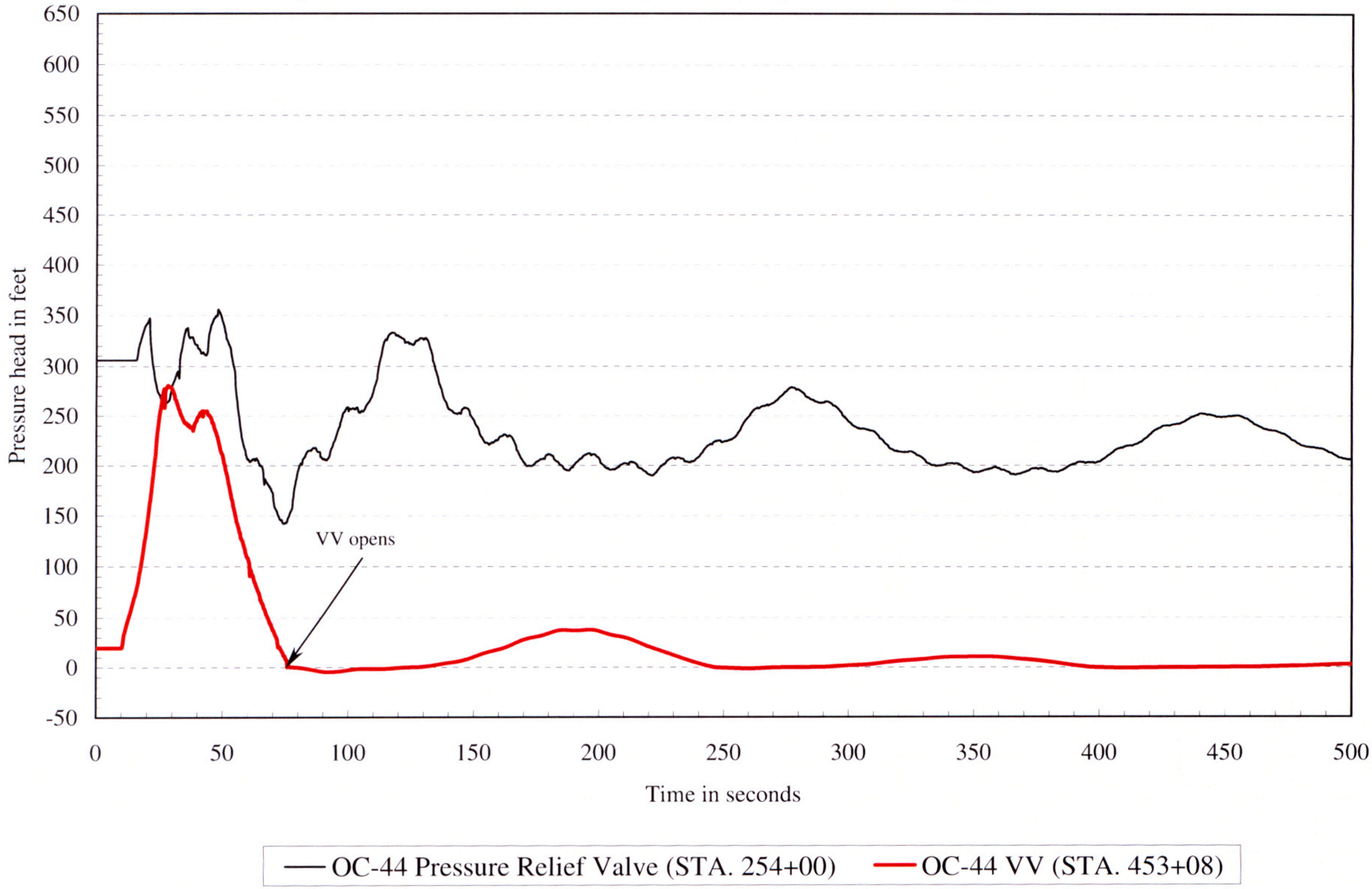

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Figure 27 - Pressure heads after loss of power to pump stations with surge protection

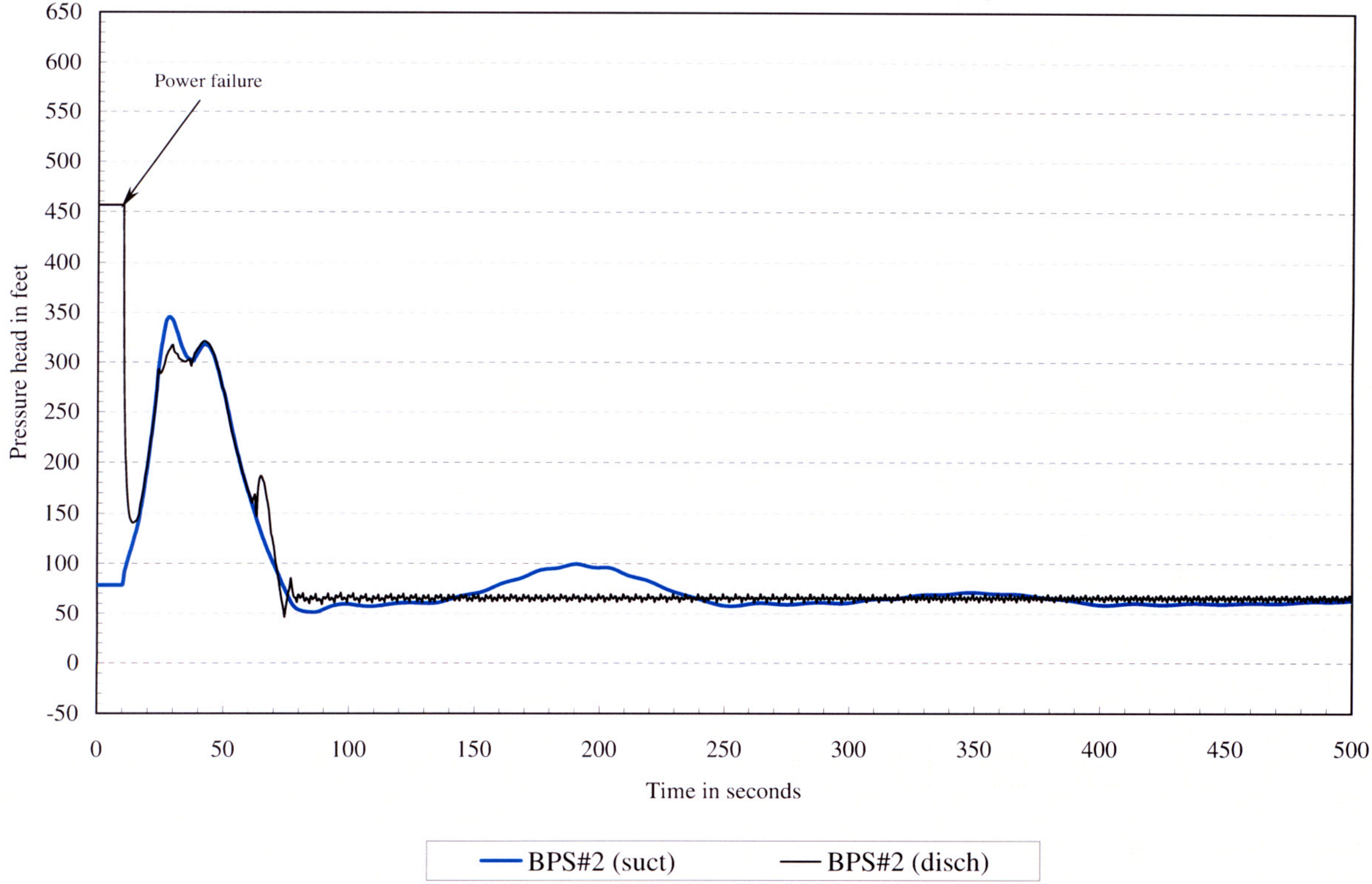

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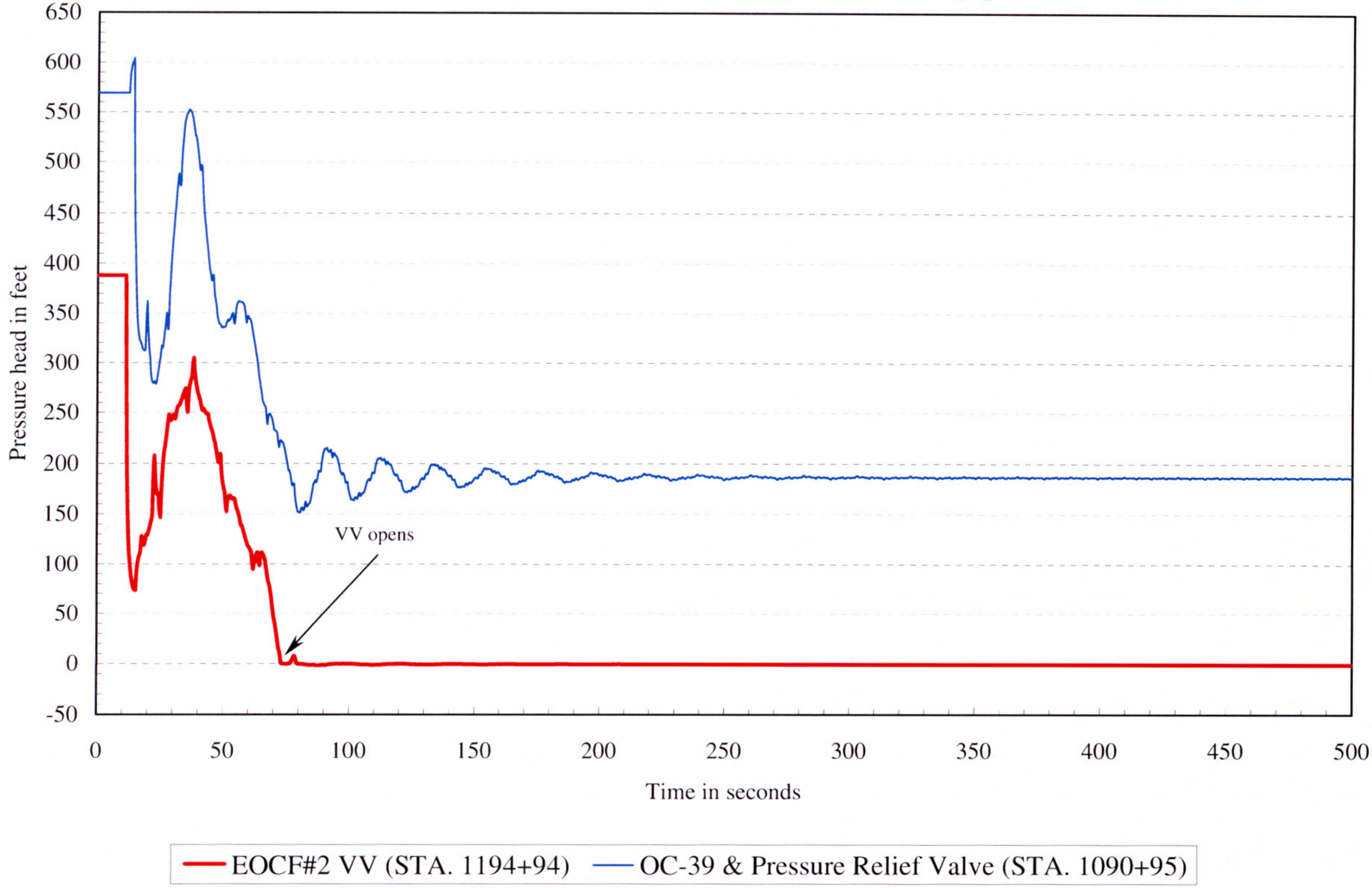
Figure 28 - Pressure heads after loss of power to pump stations with surge protection



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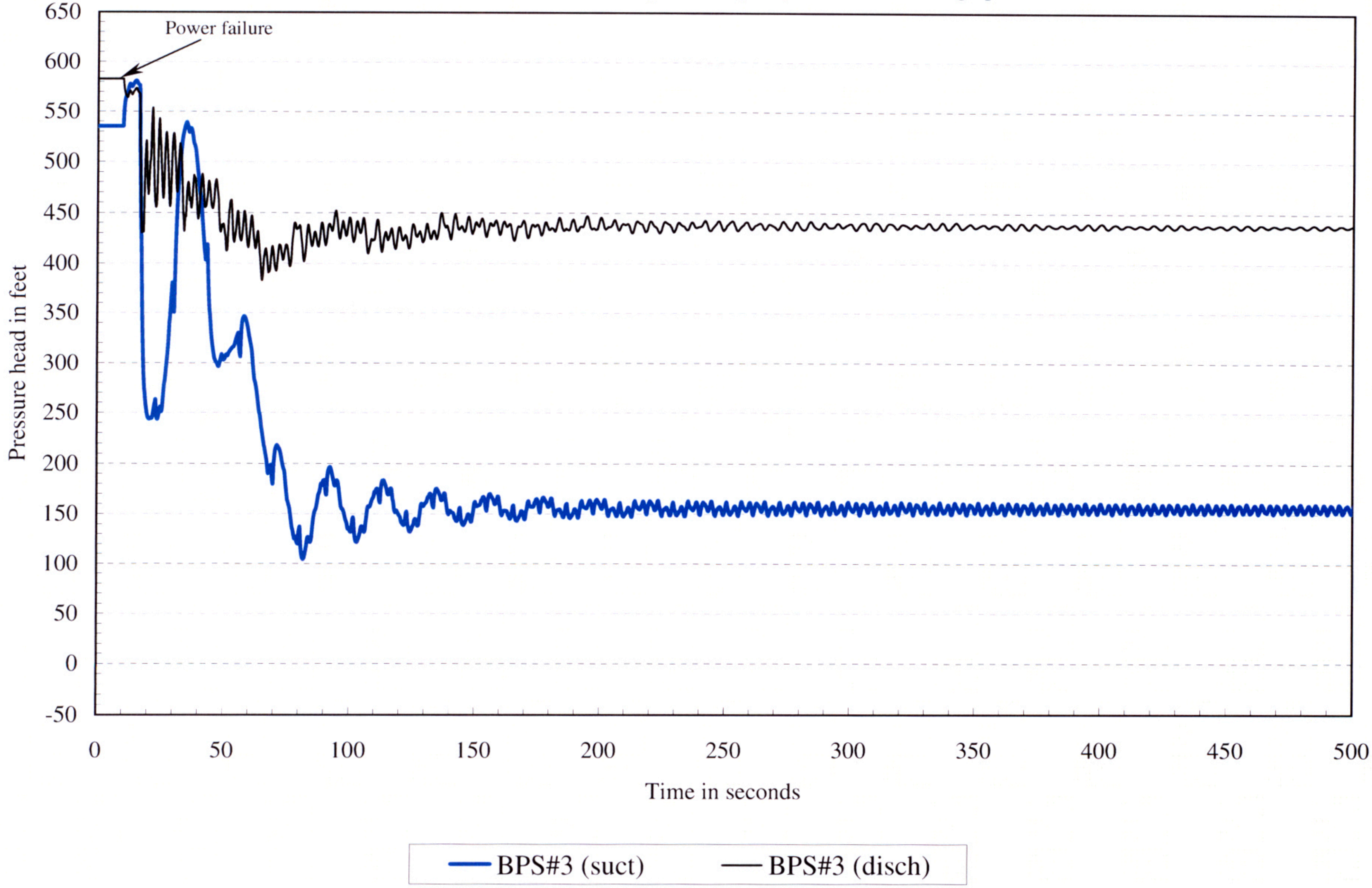
Poseidon Resources Huntington Beach Seawater Desalination Plant (48")

Figure 29 - Pressure heads after loss of power to pump stations with surge protection



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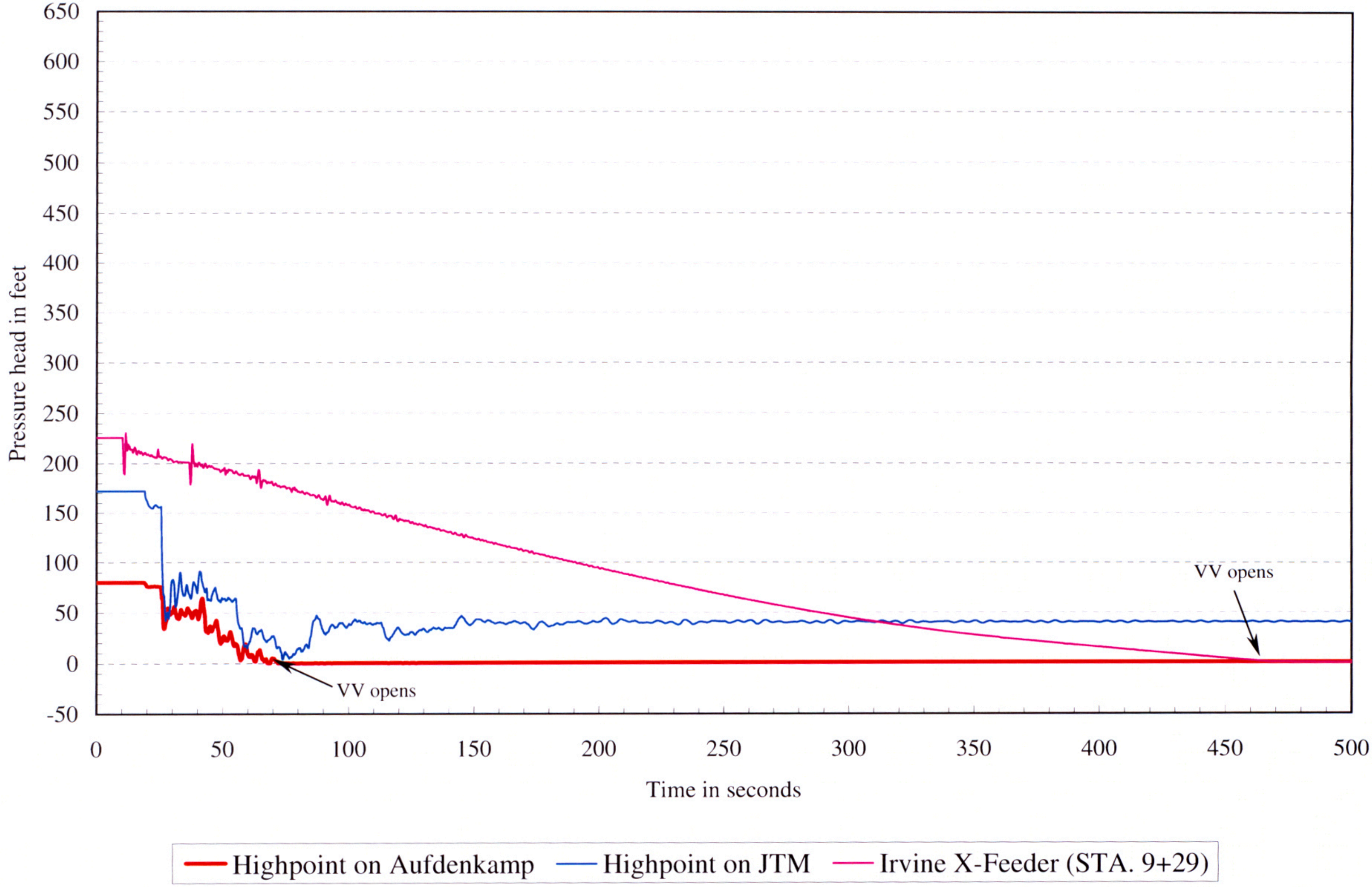
Poseidon Resources Huntington Beach Seawater Desalination Plant (48")

Figure 30 - Pressure heads after loss of power to pump stations with surge protection



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Poseidon Resources Huntington Beach Seawater Desalination Plant (48")

Figure 31 - Pressure heads after loss of power to pump stations with surge protection

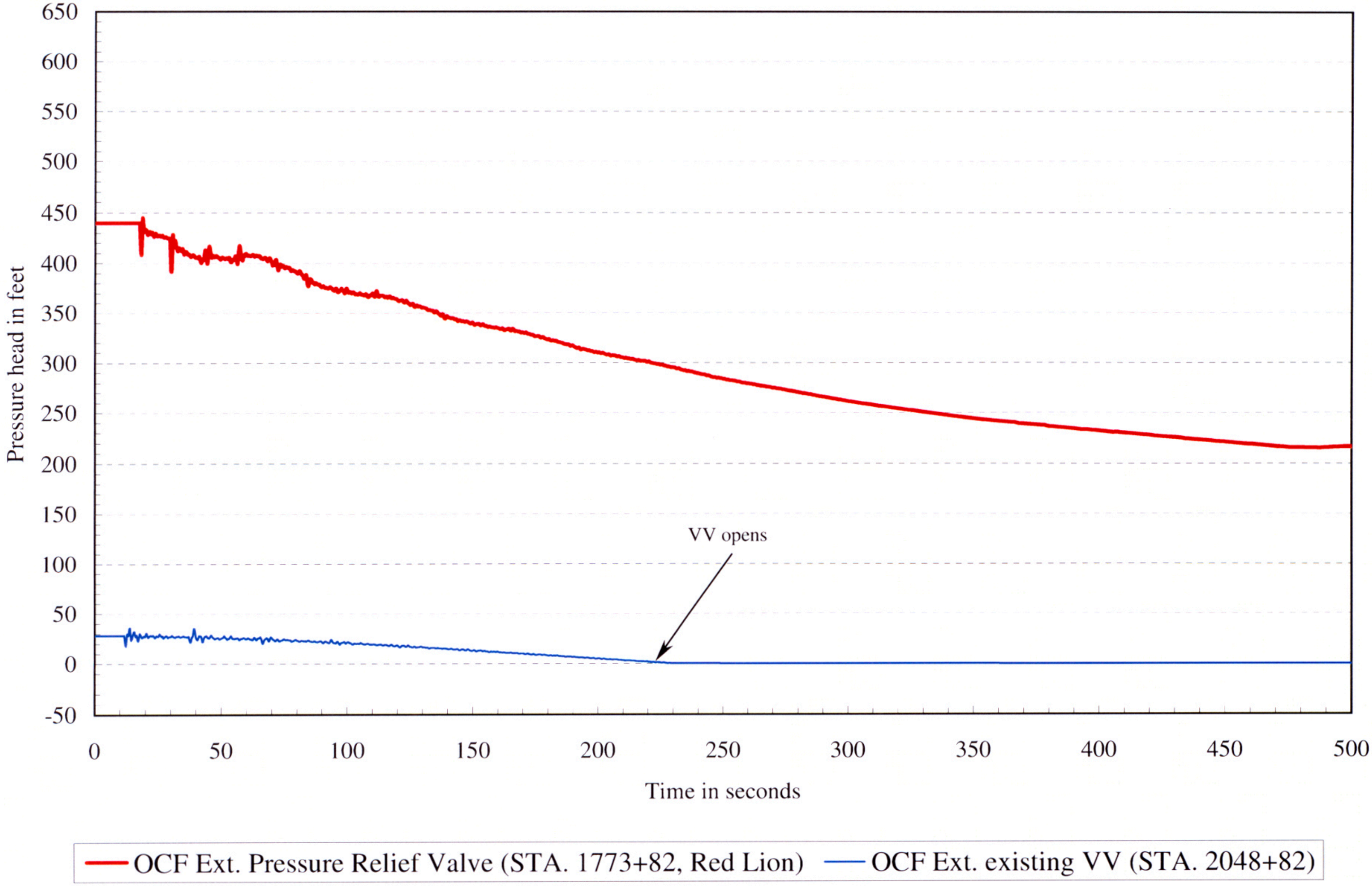

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Figure 32 - HGL's in Path A after loss of power to pump stations with surge protection

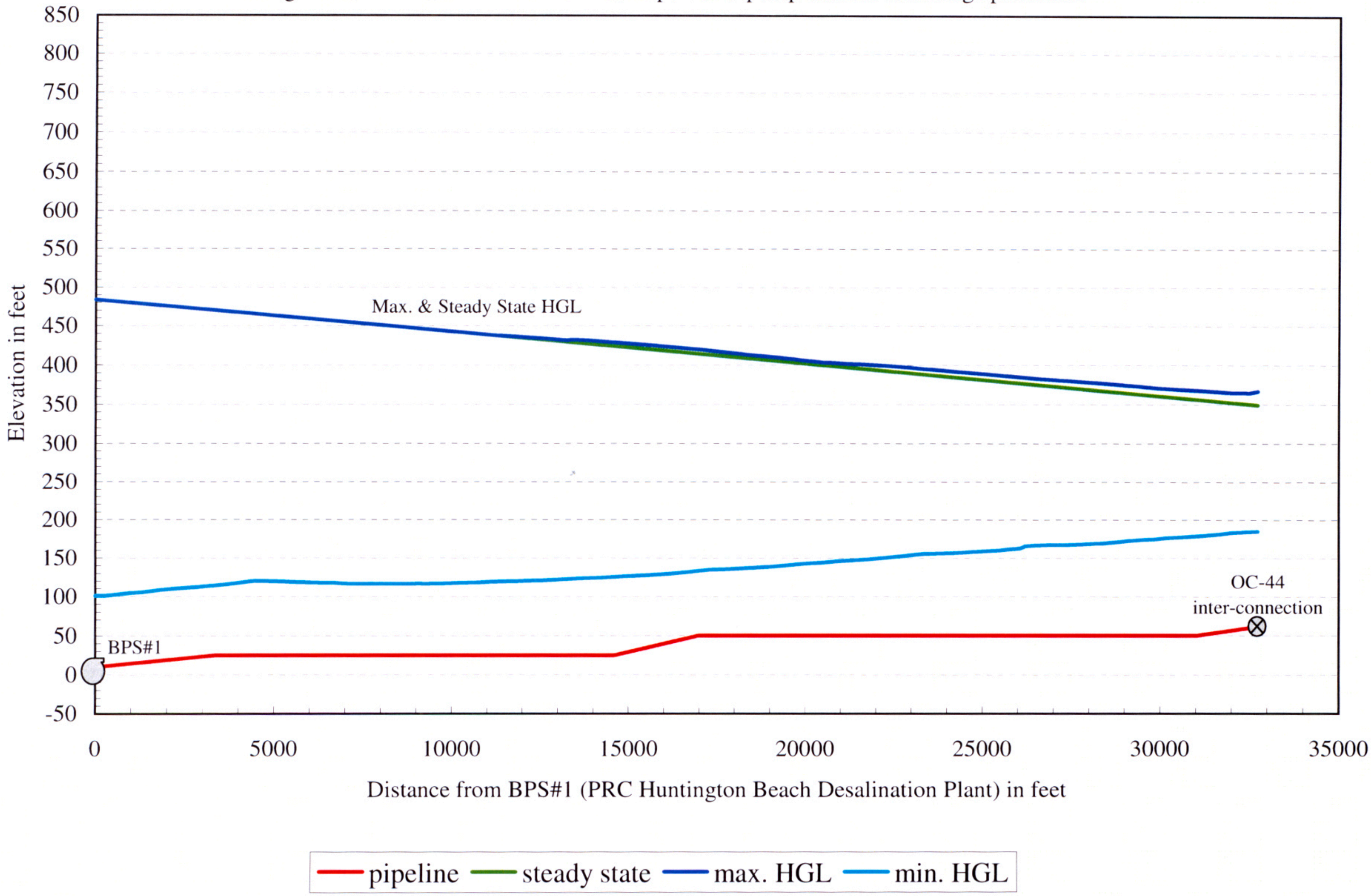

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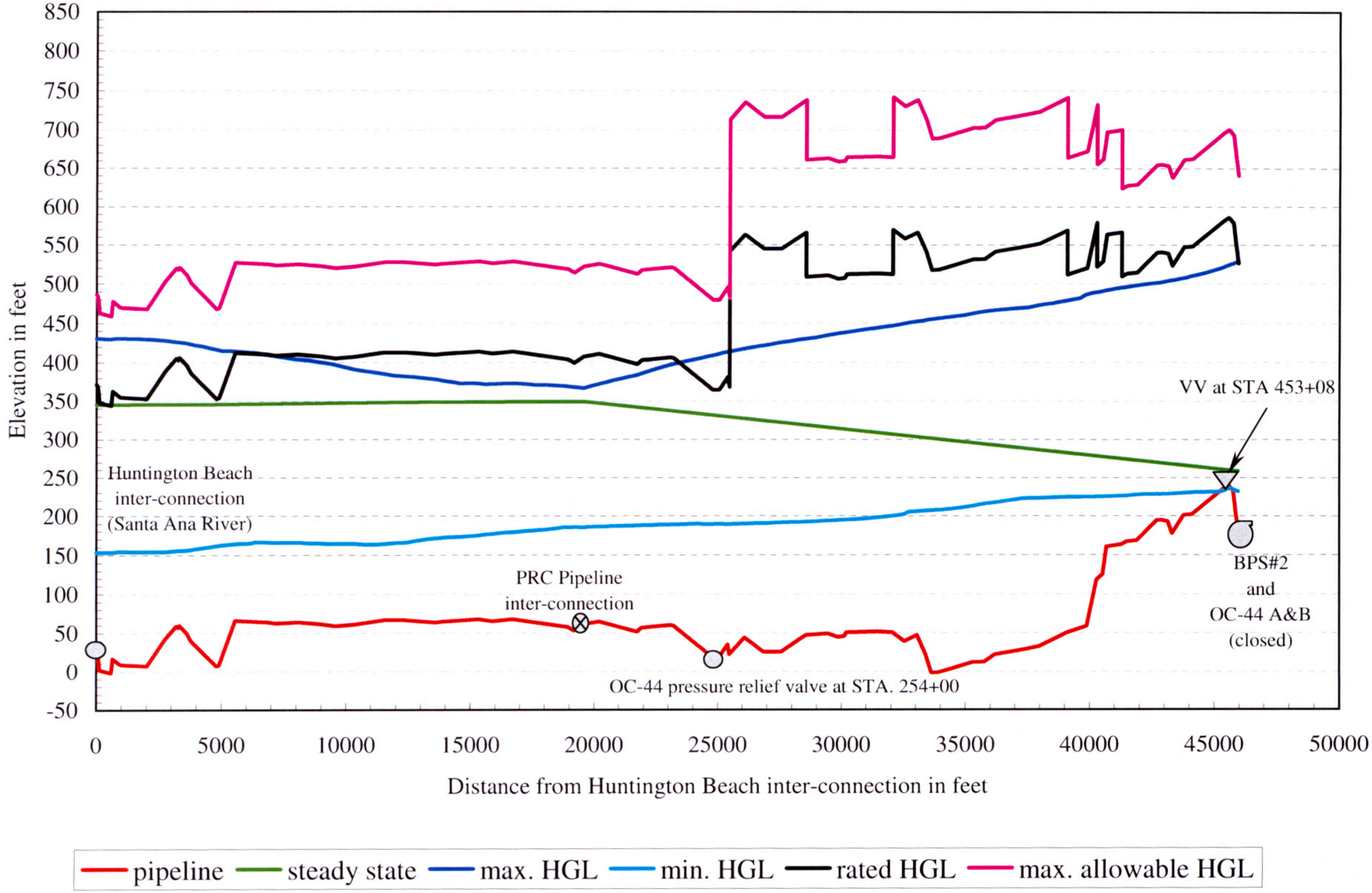
Figure 33 - HGL's in Path B after loss of power to pump stations with surge protection



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Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 34 - HGL's in Path C after loss of power to pump stations with surge protection

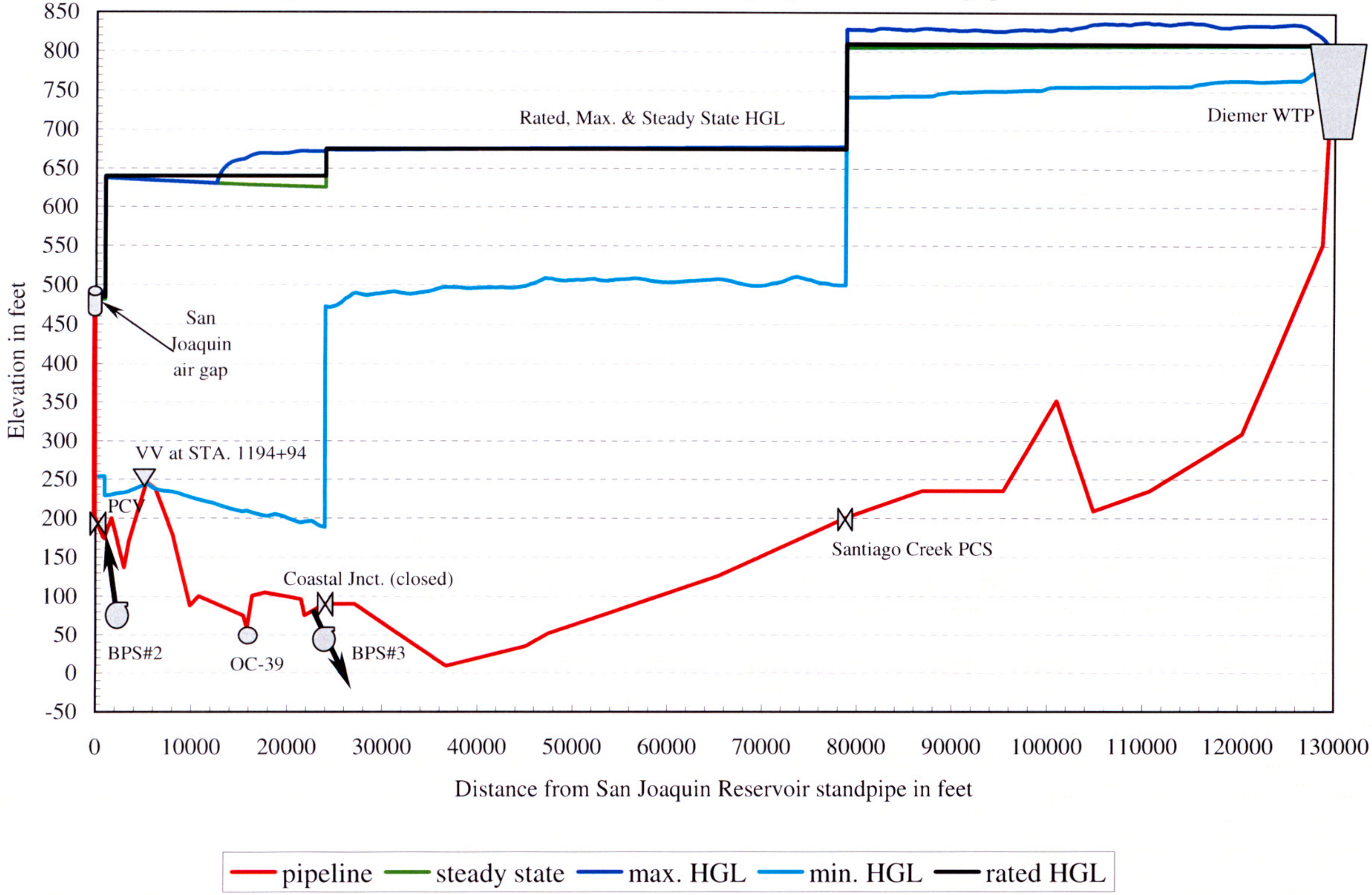

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Figure 35 - HGL's in Path D after loss of power to pump stations with surge protection

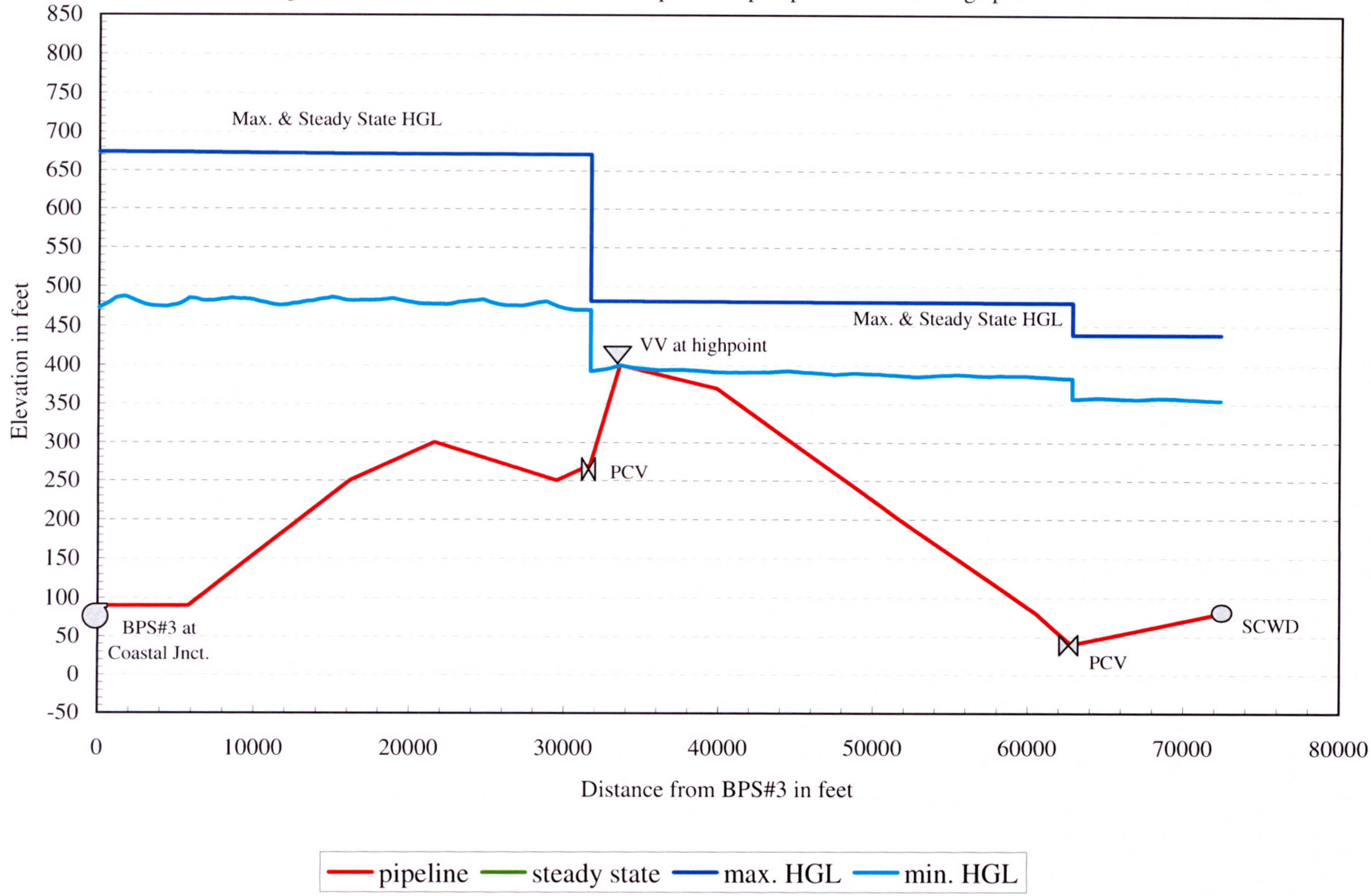

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Figure 36 - HGL's in Path E after loss of power to pump stations with surge protection

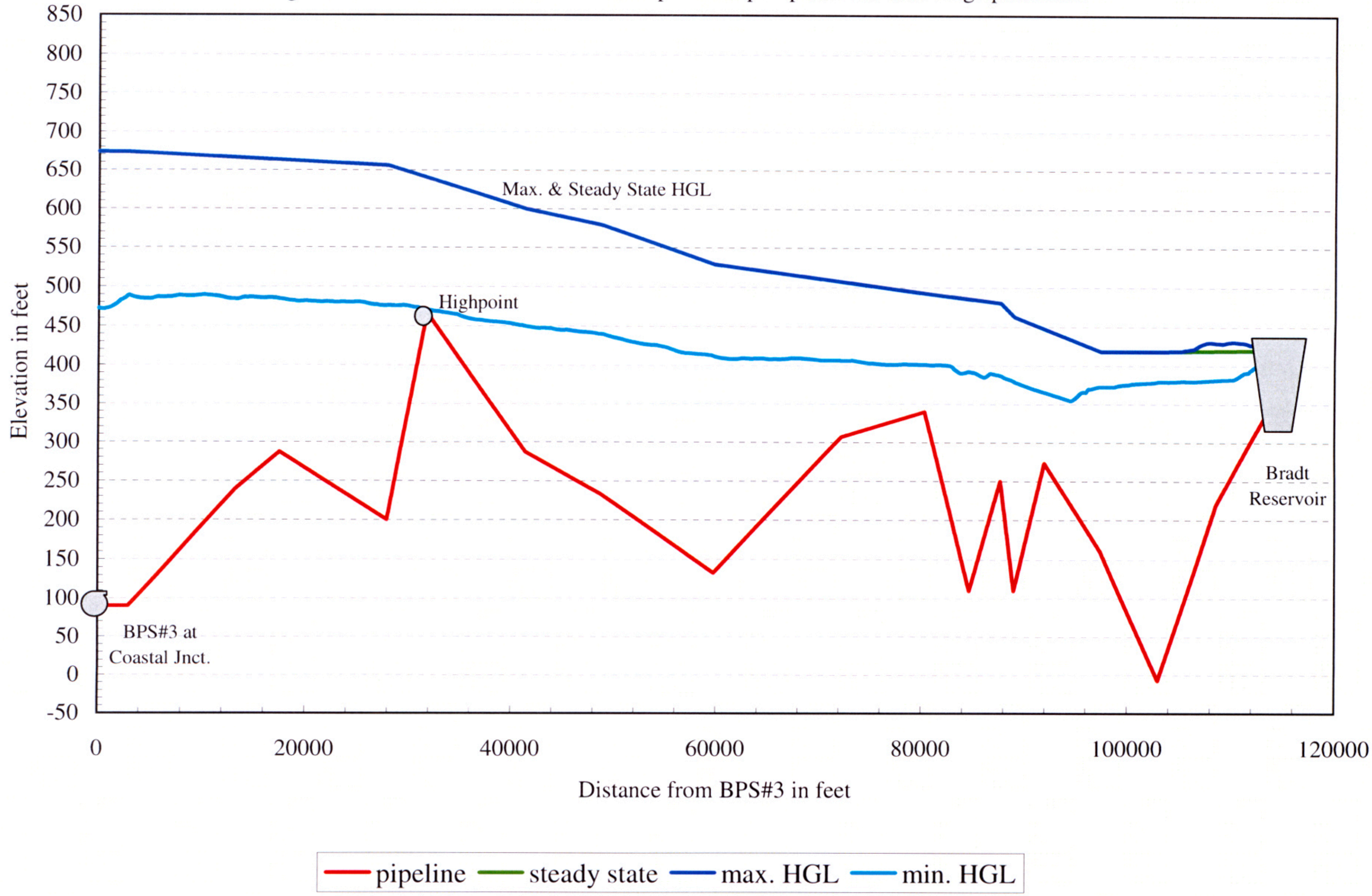

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Figure 37 - HGL's in Path F after loss of power to pump stations with surge protection

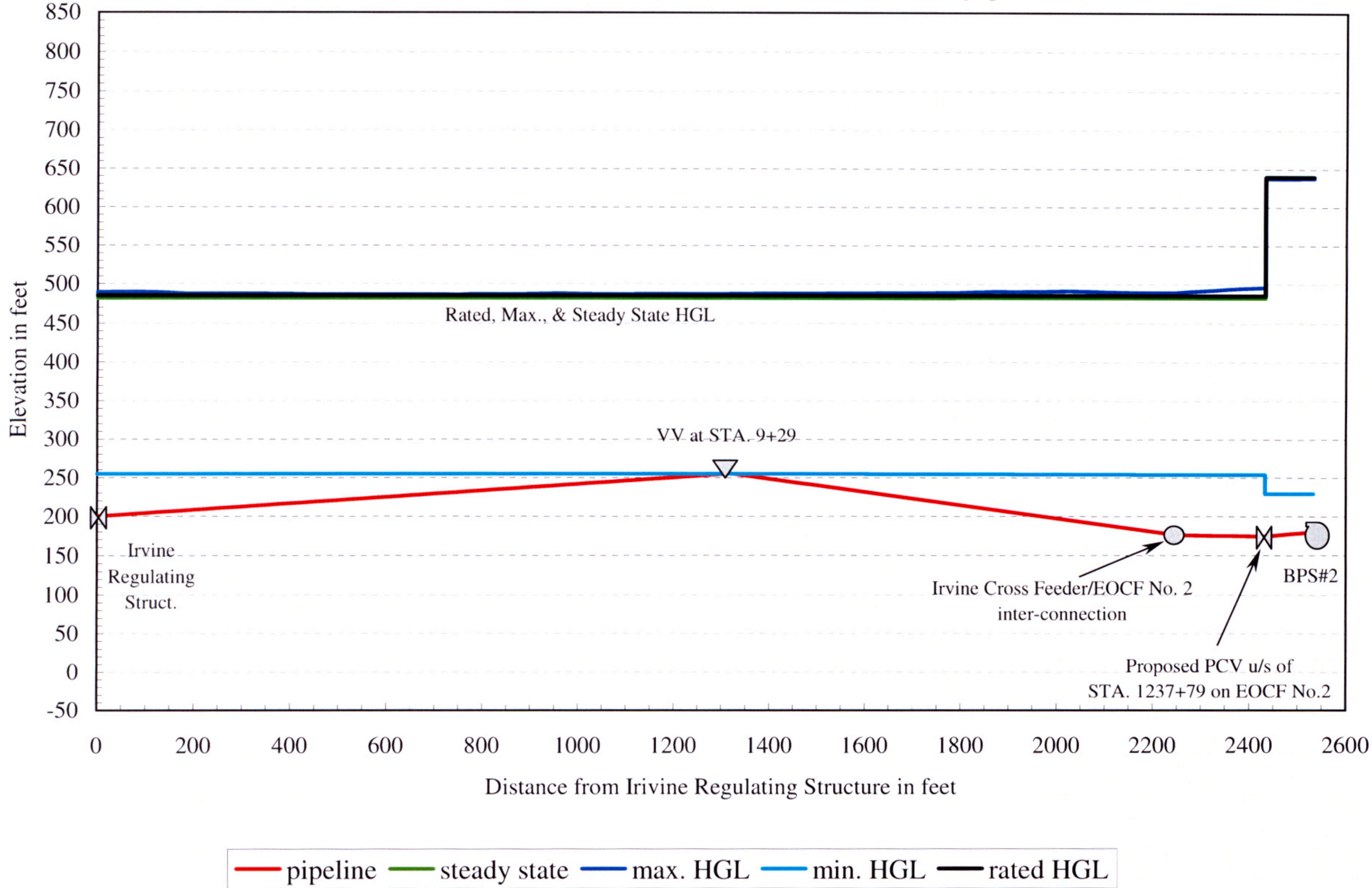

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Figure 38 - HGL's in Path G after loss of power to pump stations with surge protection

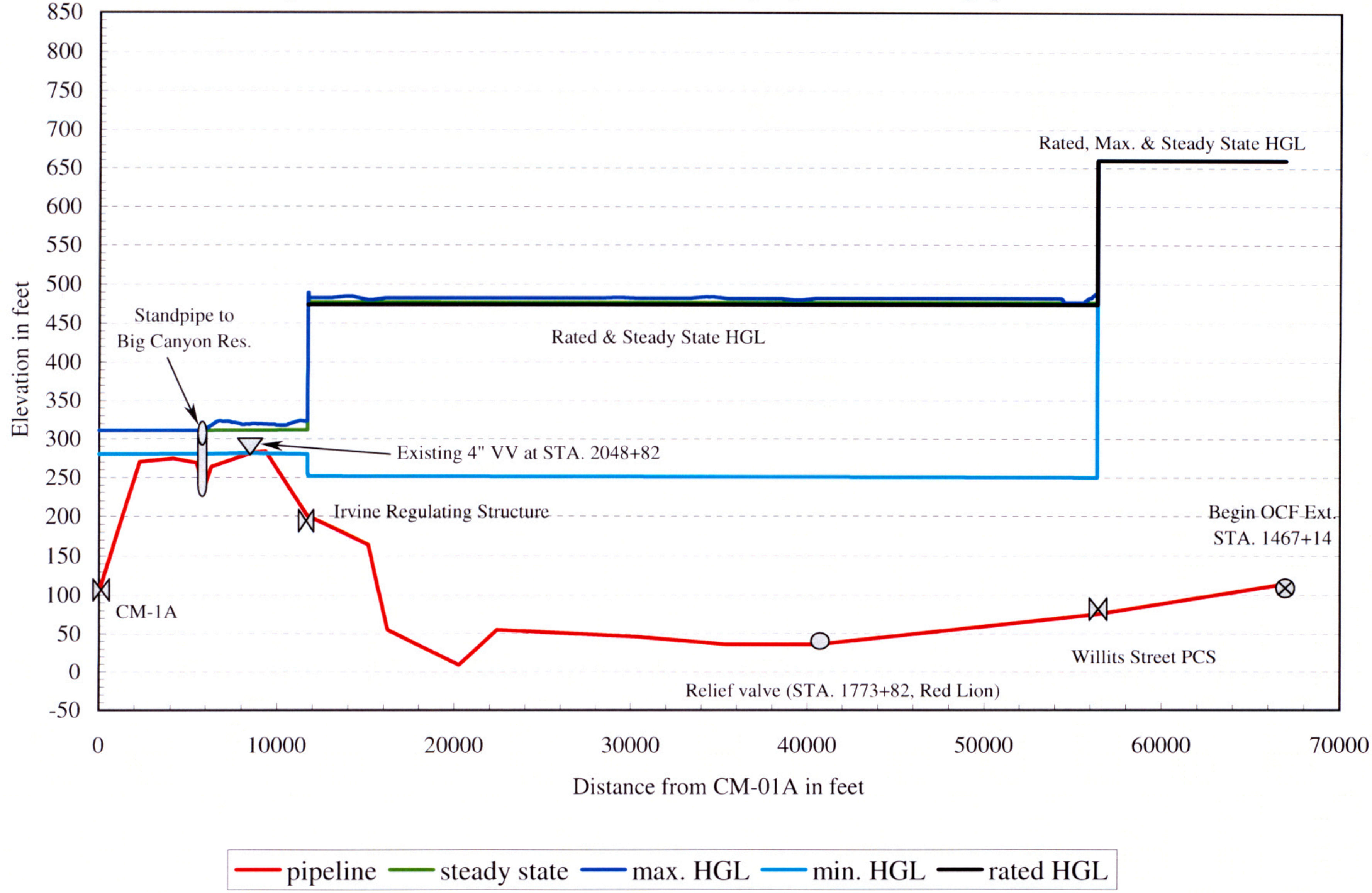

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Figure 39 - HGL's in Path H after loss of power to pump stations with surge protection

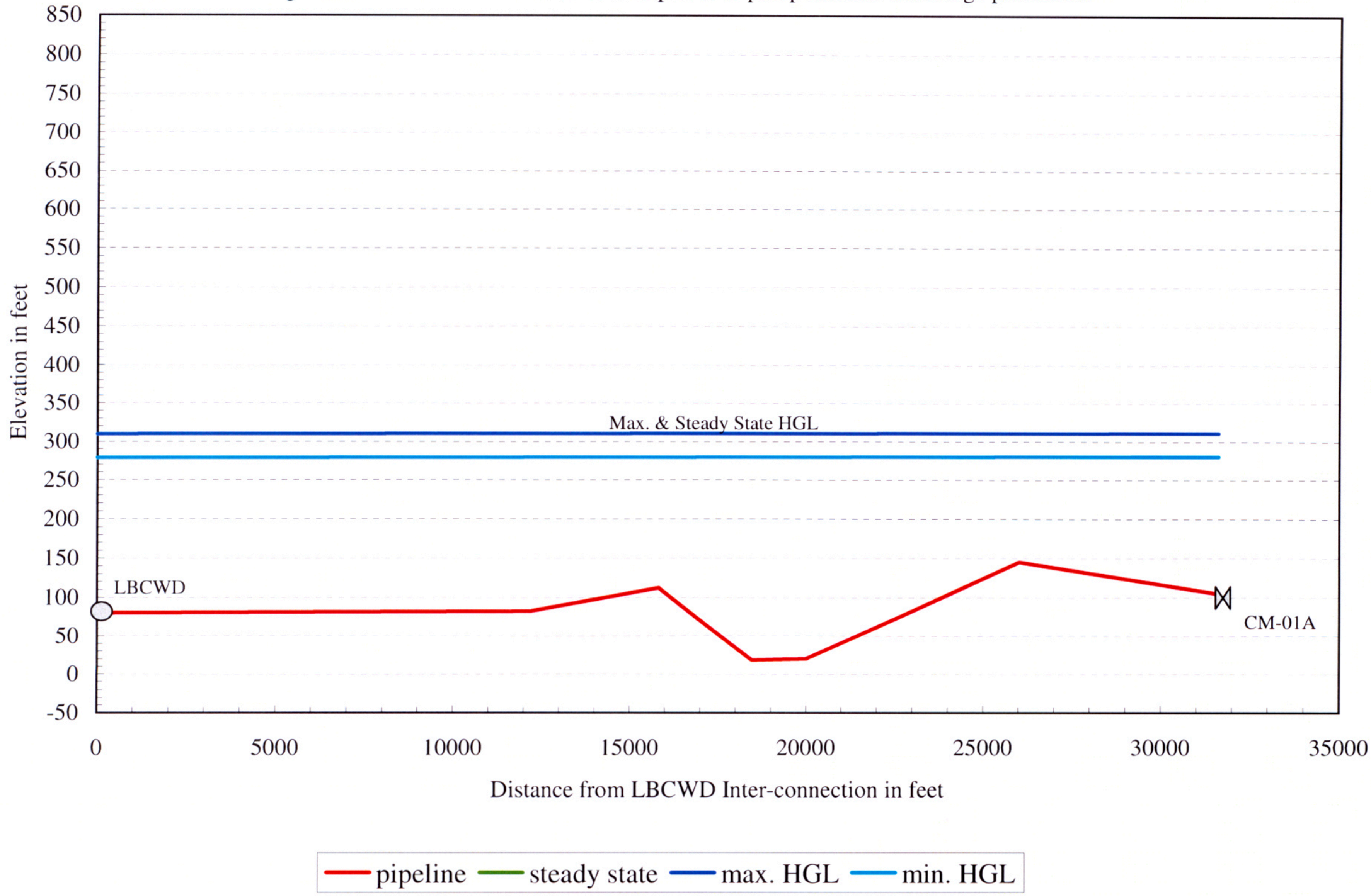

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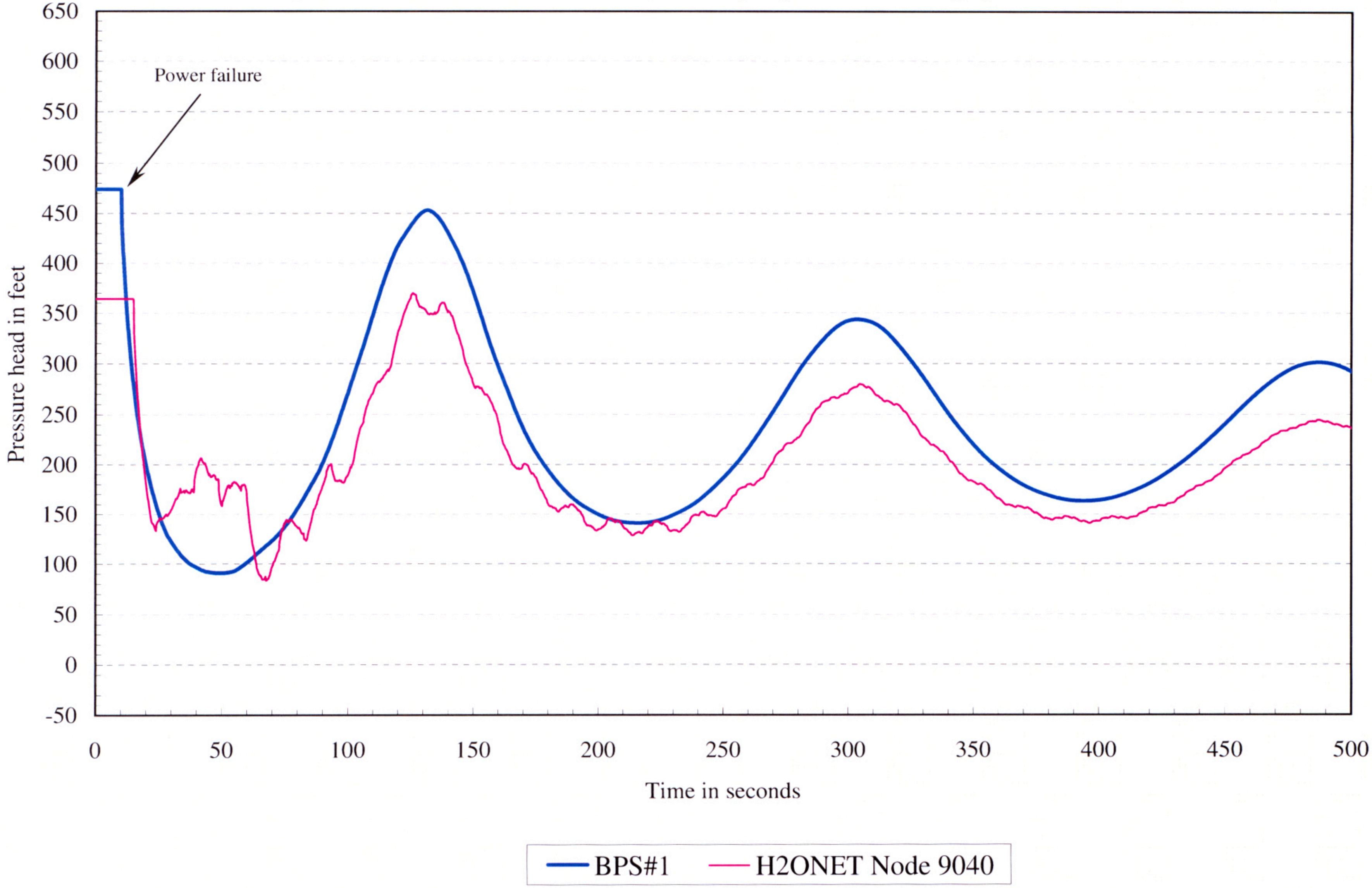
Figure 40 - Pressure heads after loss of power to pump stations with surge protection



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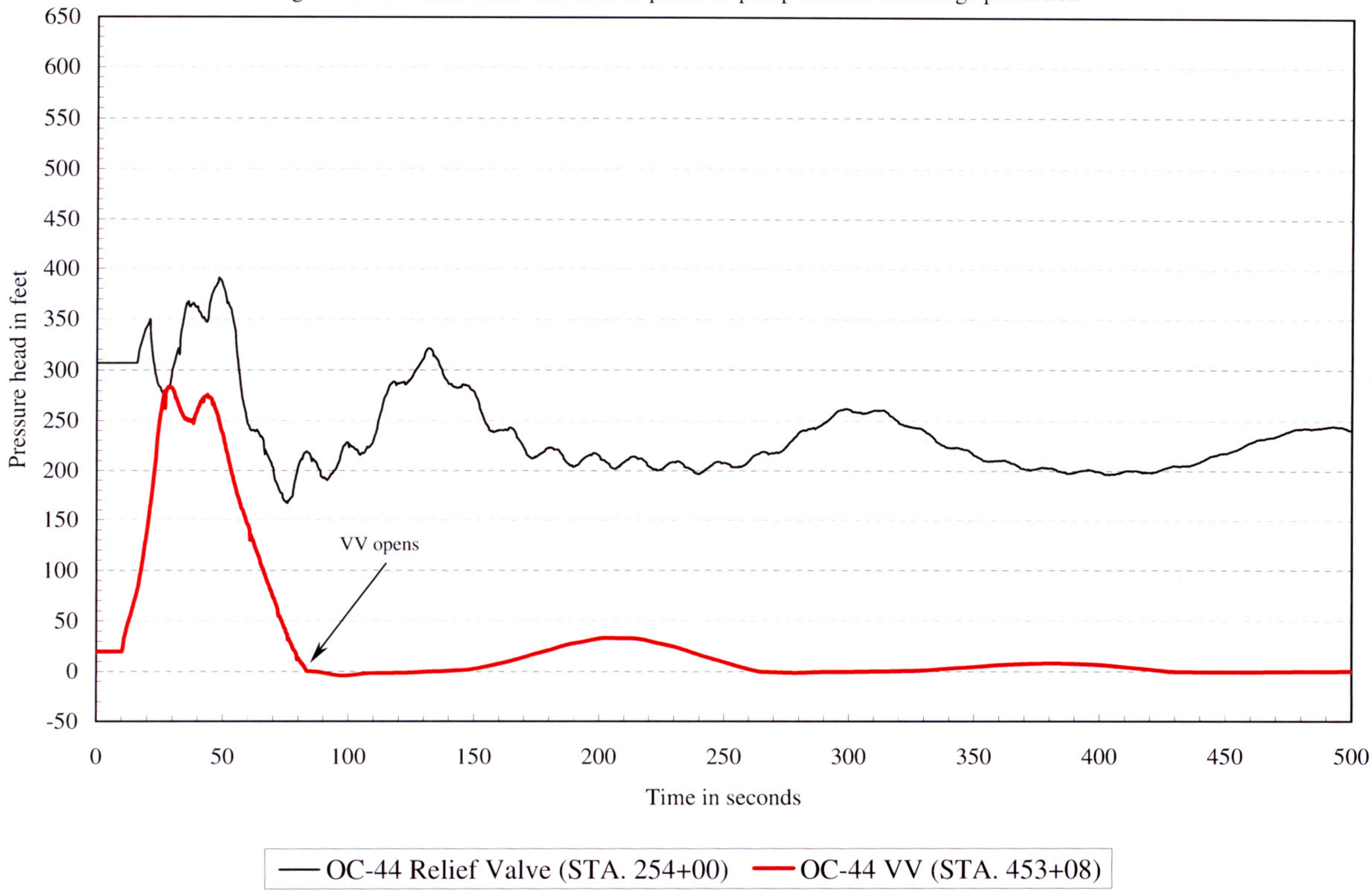
Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 41 - Pressure heads after loss of power to pump stations with surge protection



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Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 42 - Pressure heads after loss of power to pump stations with surge protection

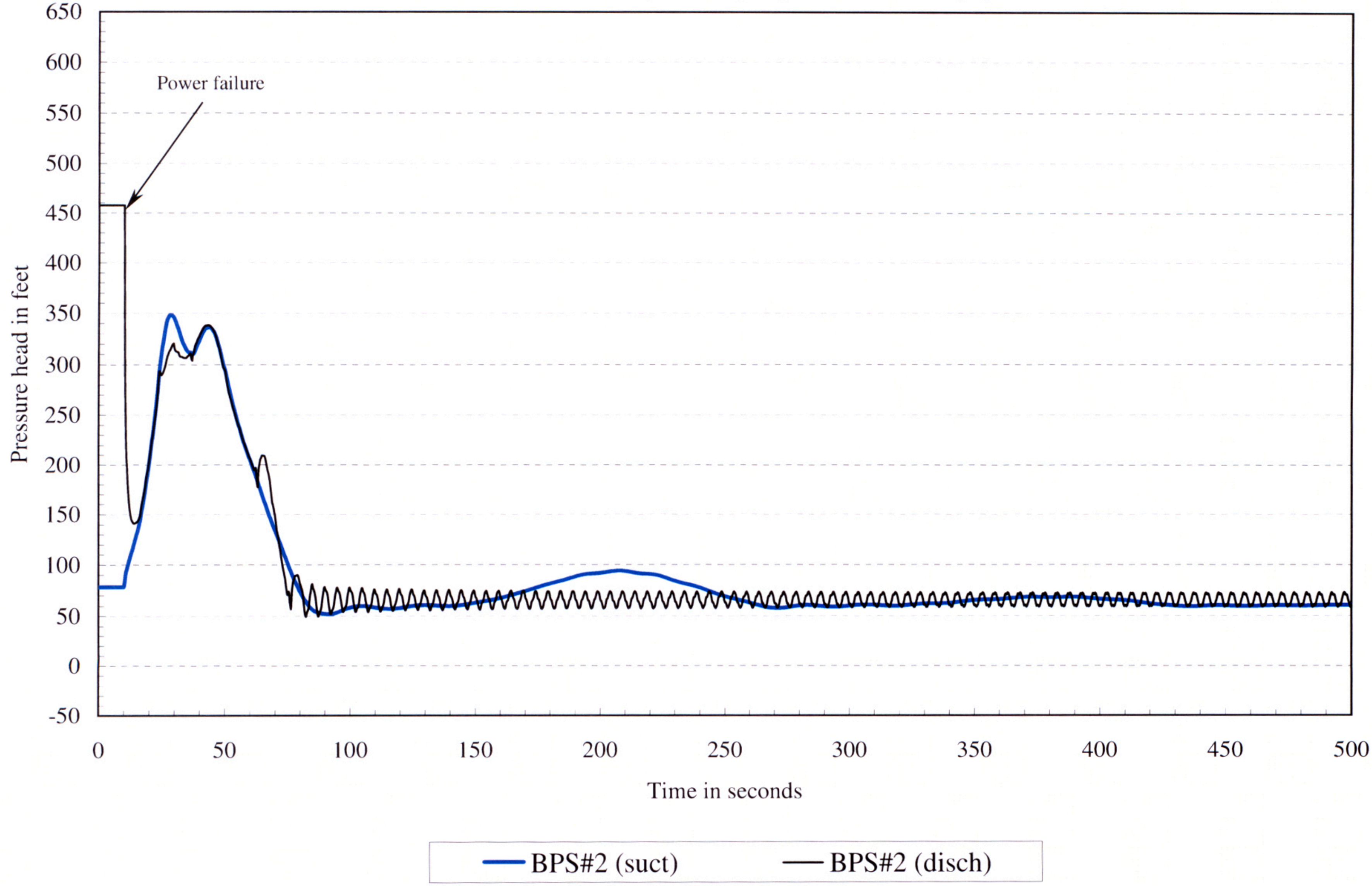

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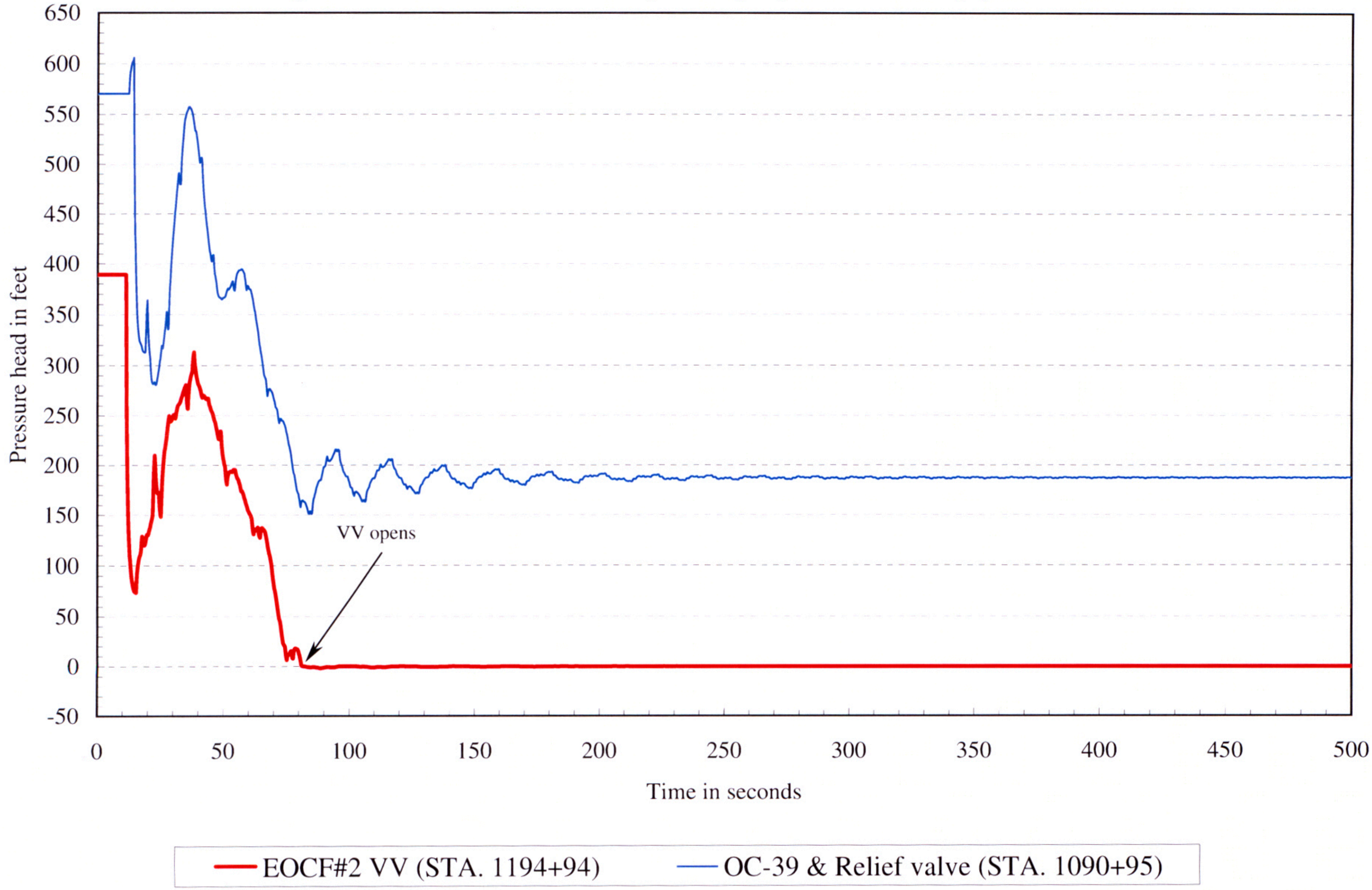
Figure 43 - Pressure heads after loss of power to pump stations with surge protection



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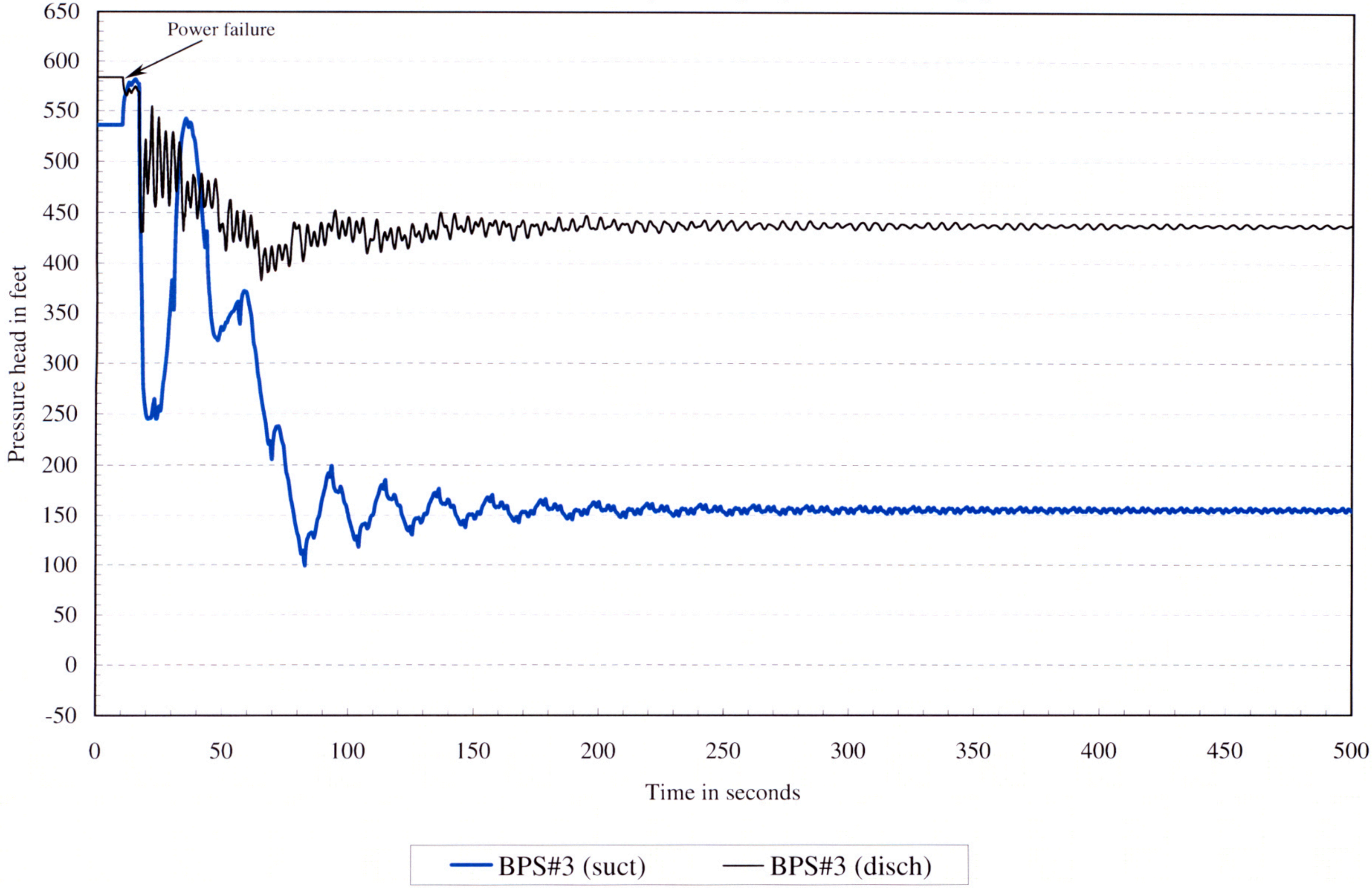
Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 44 - Pressure heads after loss of power to pump stations with surge protection



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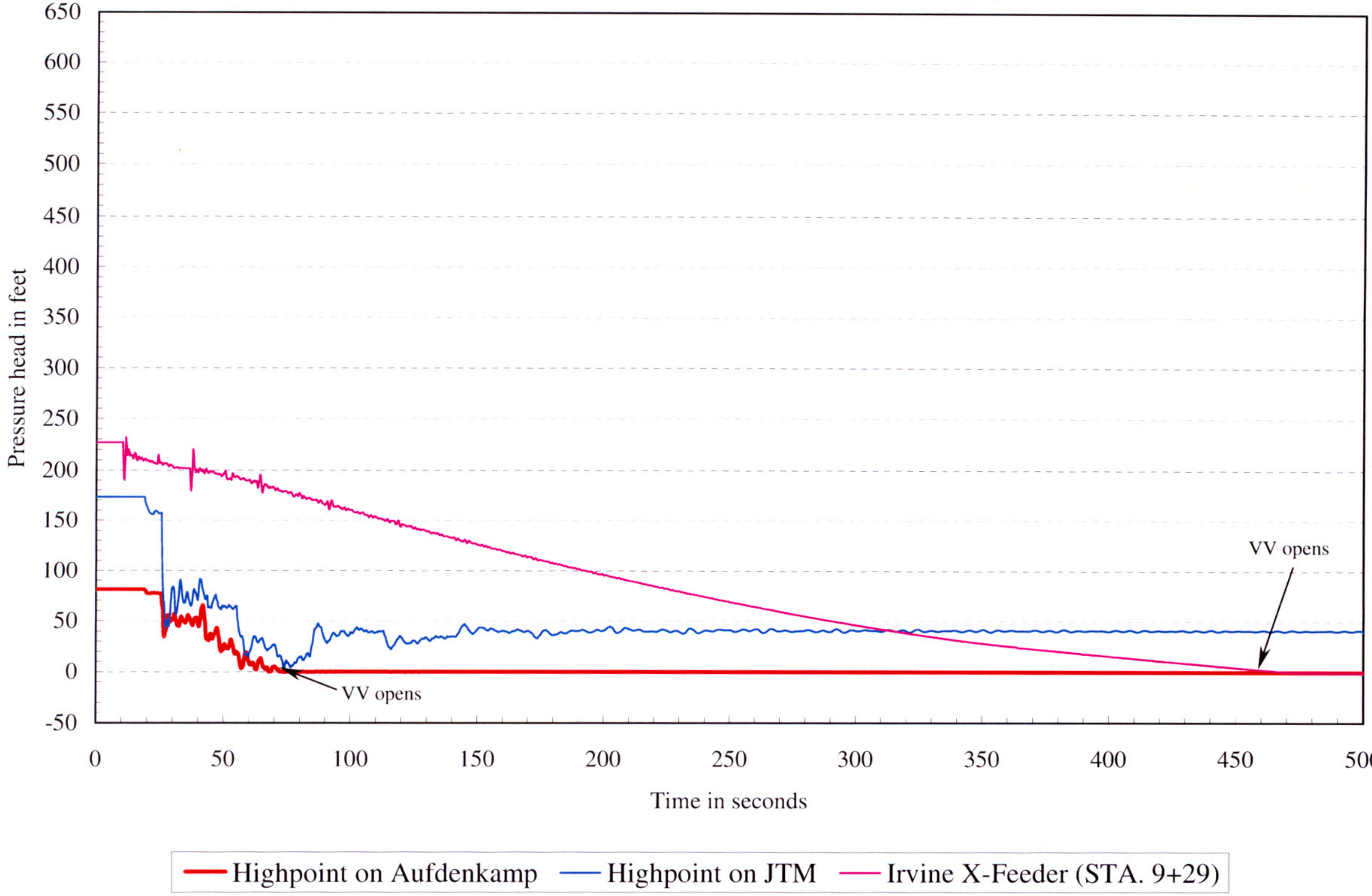
Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 45 - Pressure heads after loss of power to pump stations with surge protection



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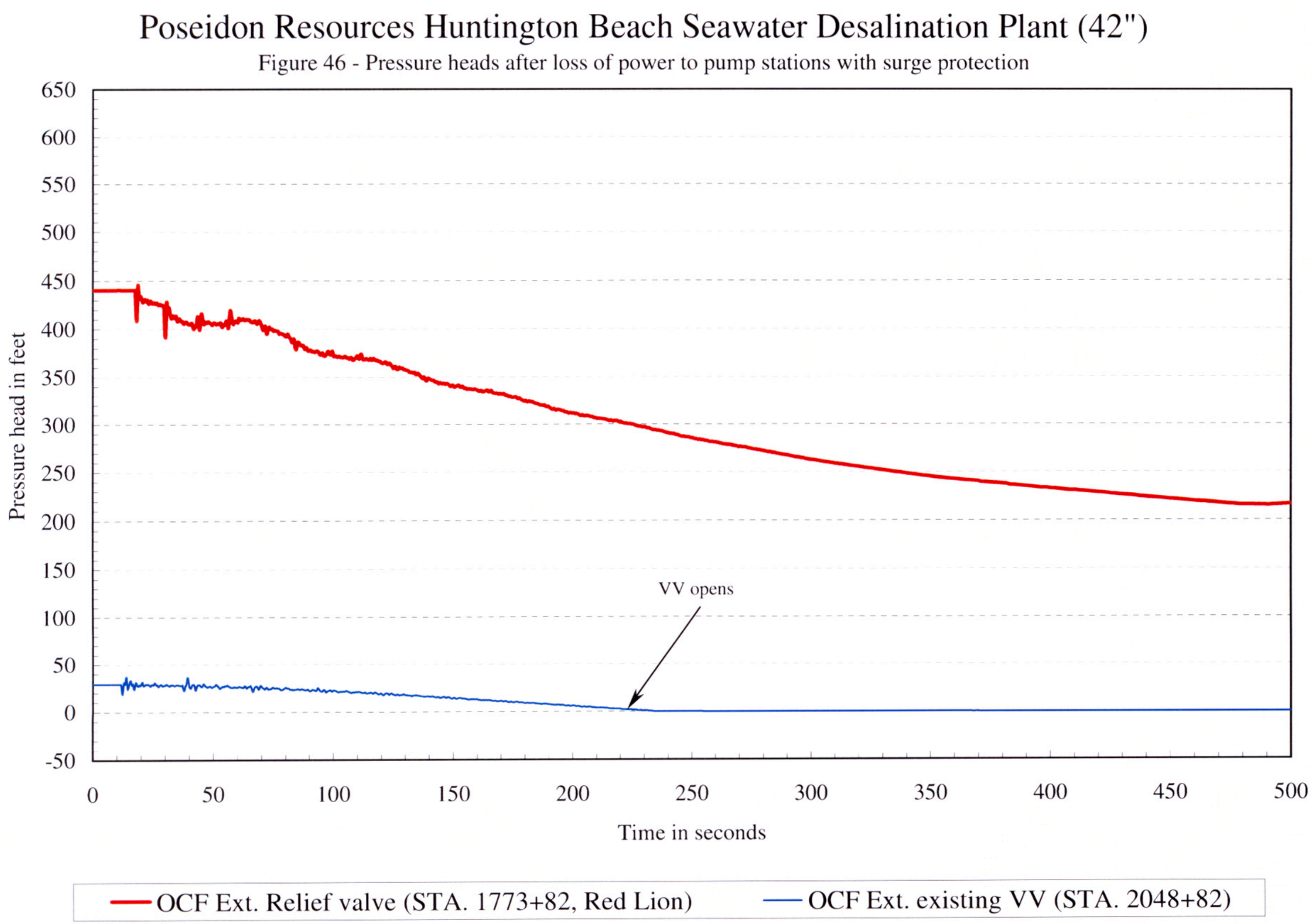
Poseidon Resources Huntington Beach Seawater Desalination Plant (42")
Figure 46 - Pressure heads after loss of power to pump stations with surge protection
Pressure head in feet
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
300
350
400
450
500
Time in seconds
VV opens
OCF Ext. Relief valve (STA. 1773+82, Red Lion)
OCF Ext. existing VV (STA. 2048+82)

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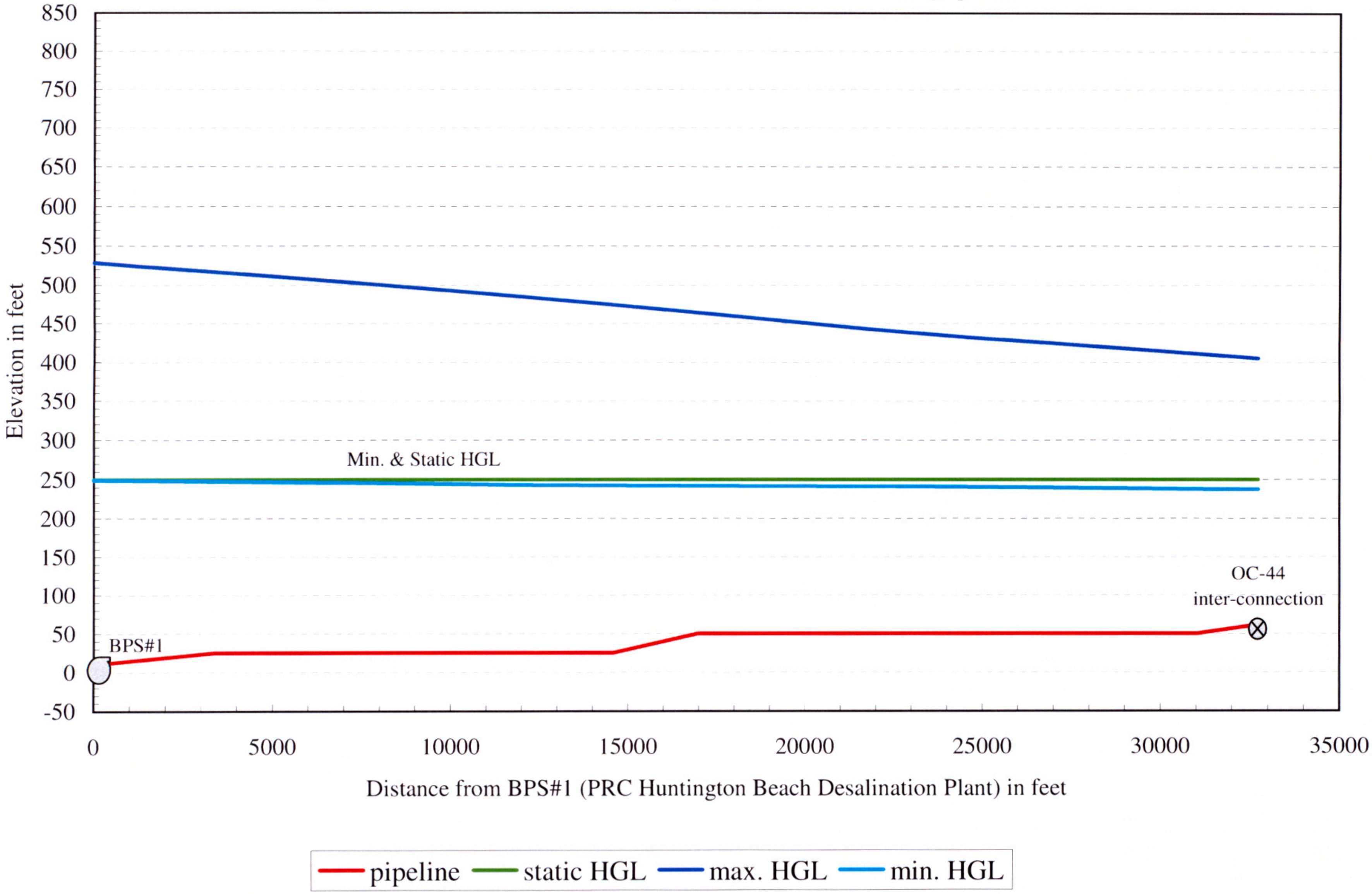
Figure 47 - HGL's in Path A after startup at pump stations with surge protection



Poseidon Resources Huntington Beach Seawater Desalination Plant (42")

Figure 48 - HGL's in Path B after startup at pump stations with surge protection

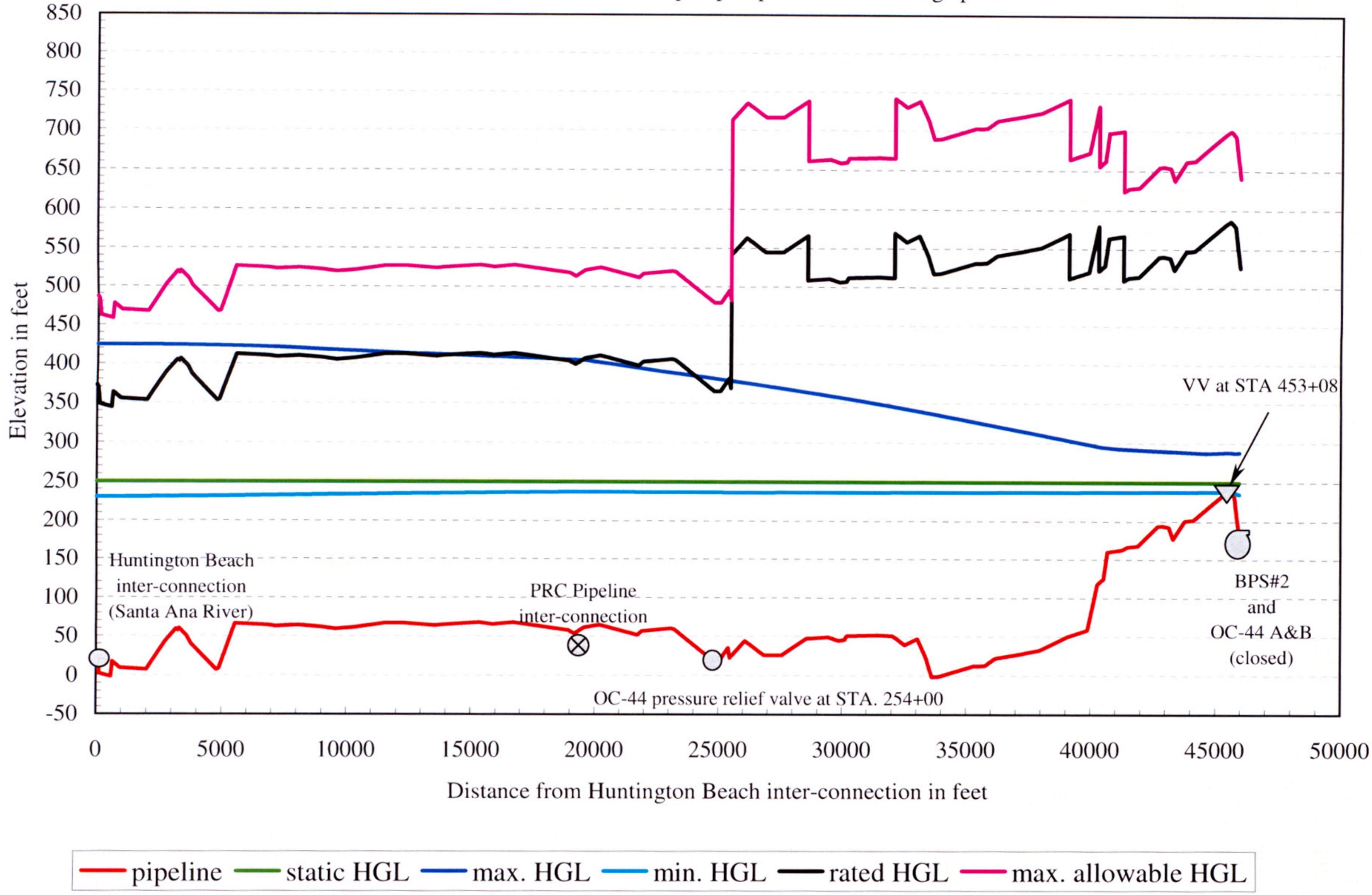


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Figure 49 - HGL's in EOCF#2 after startup at pump stations with surge protection

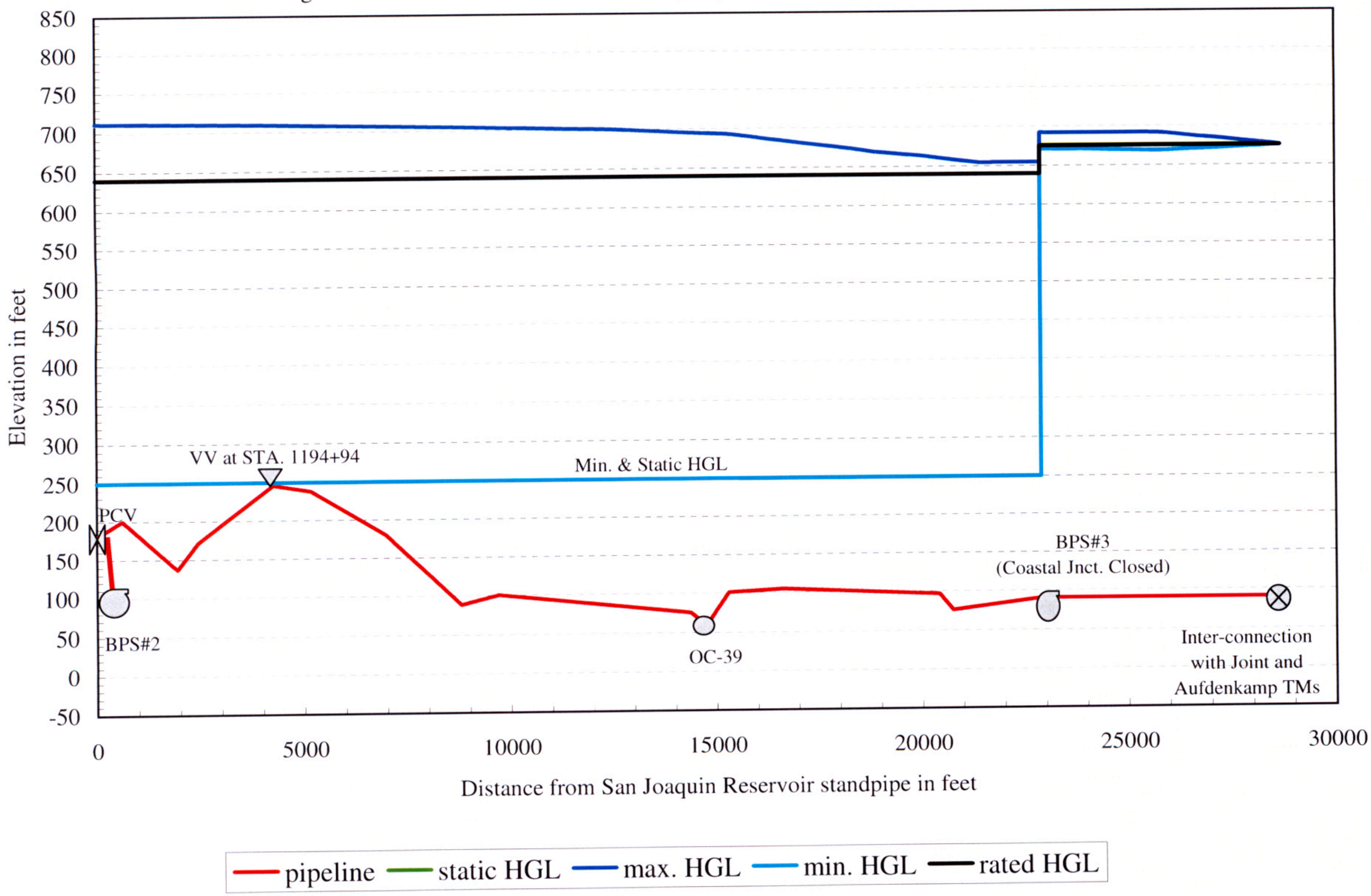

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Figure 50 - Pressure heads after startup at pump stations with surge protection

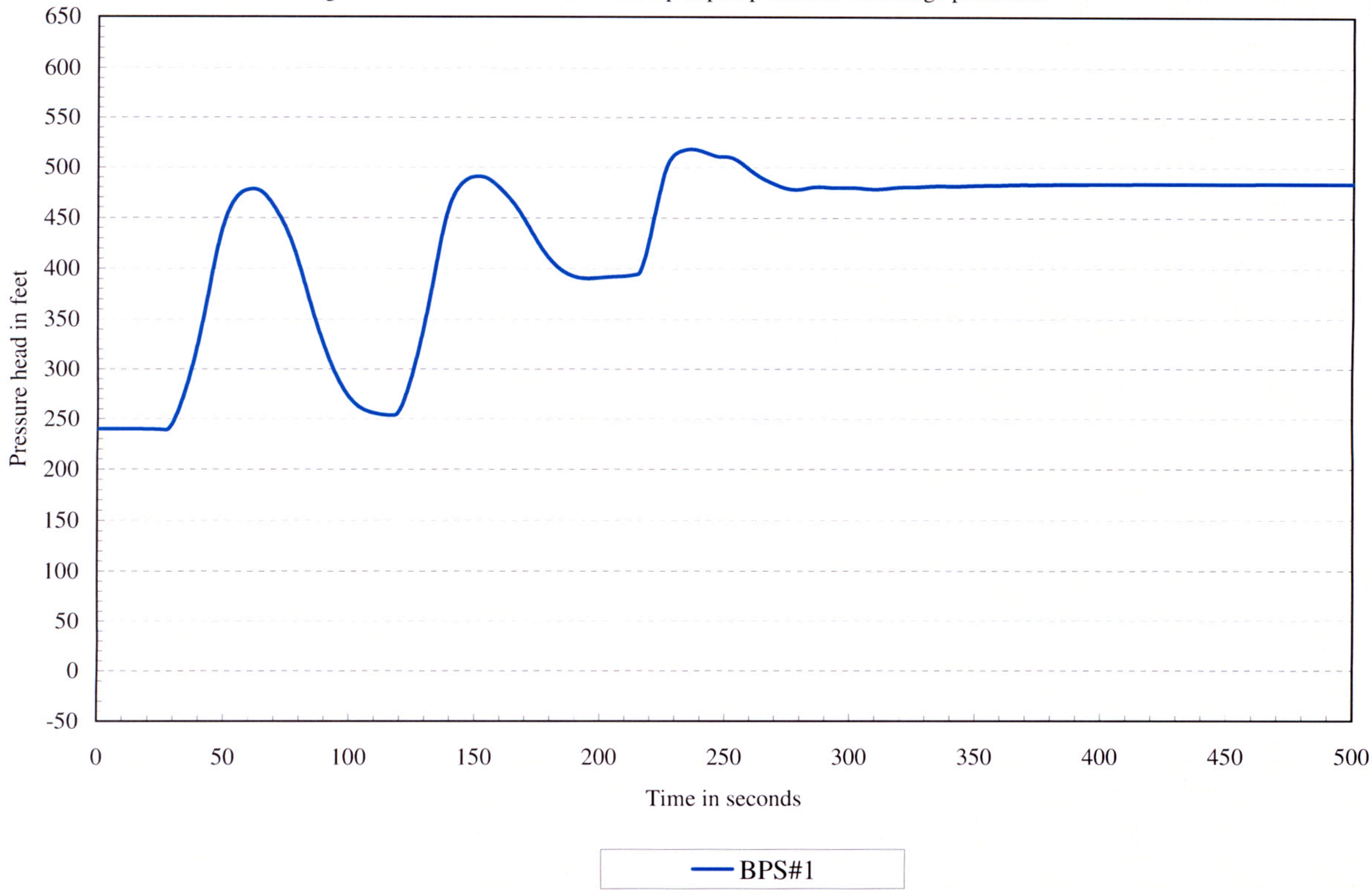

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Figure 51 - Pressure heads after startup at pump stations with surge protection

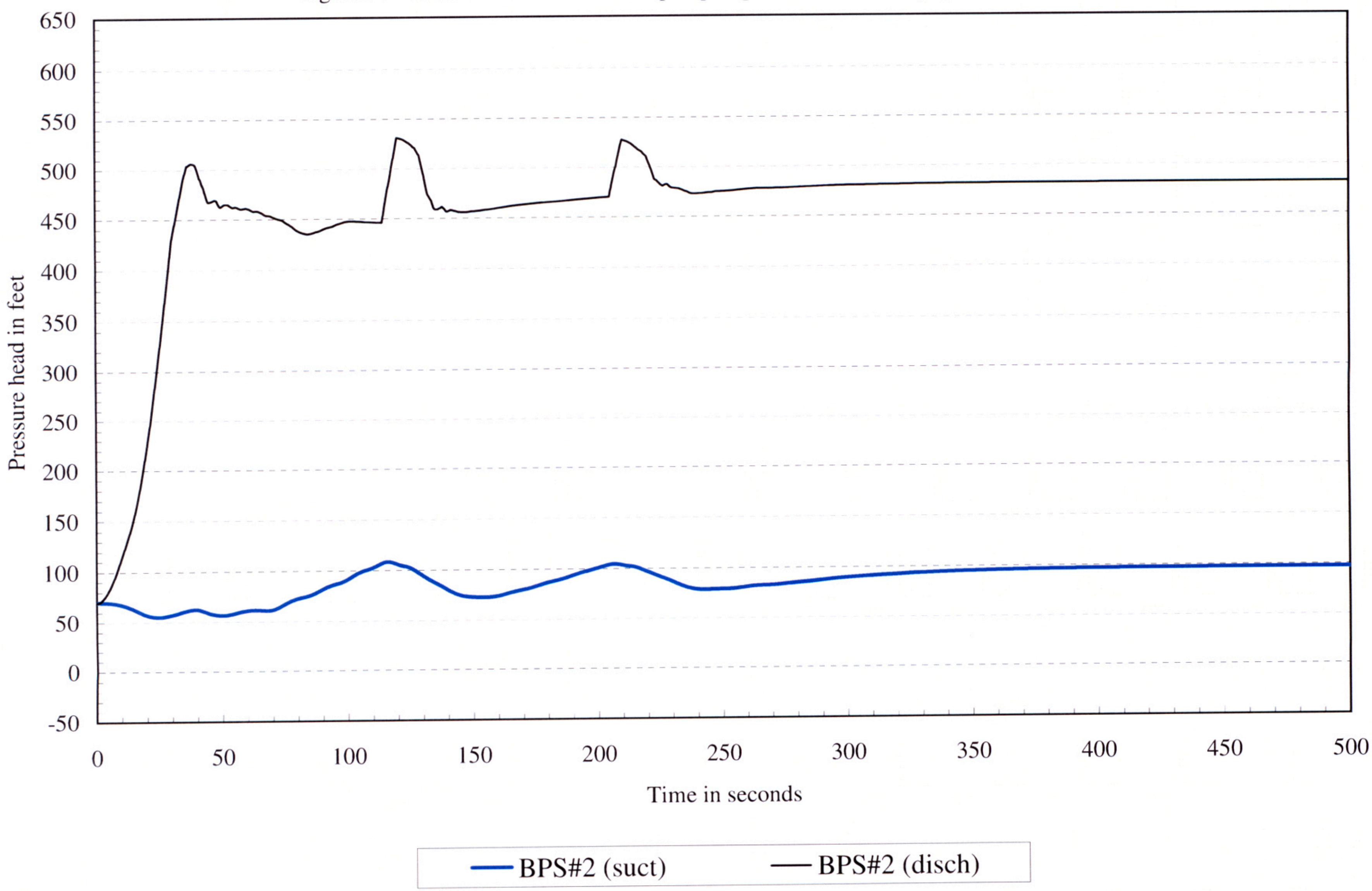

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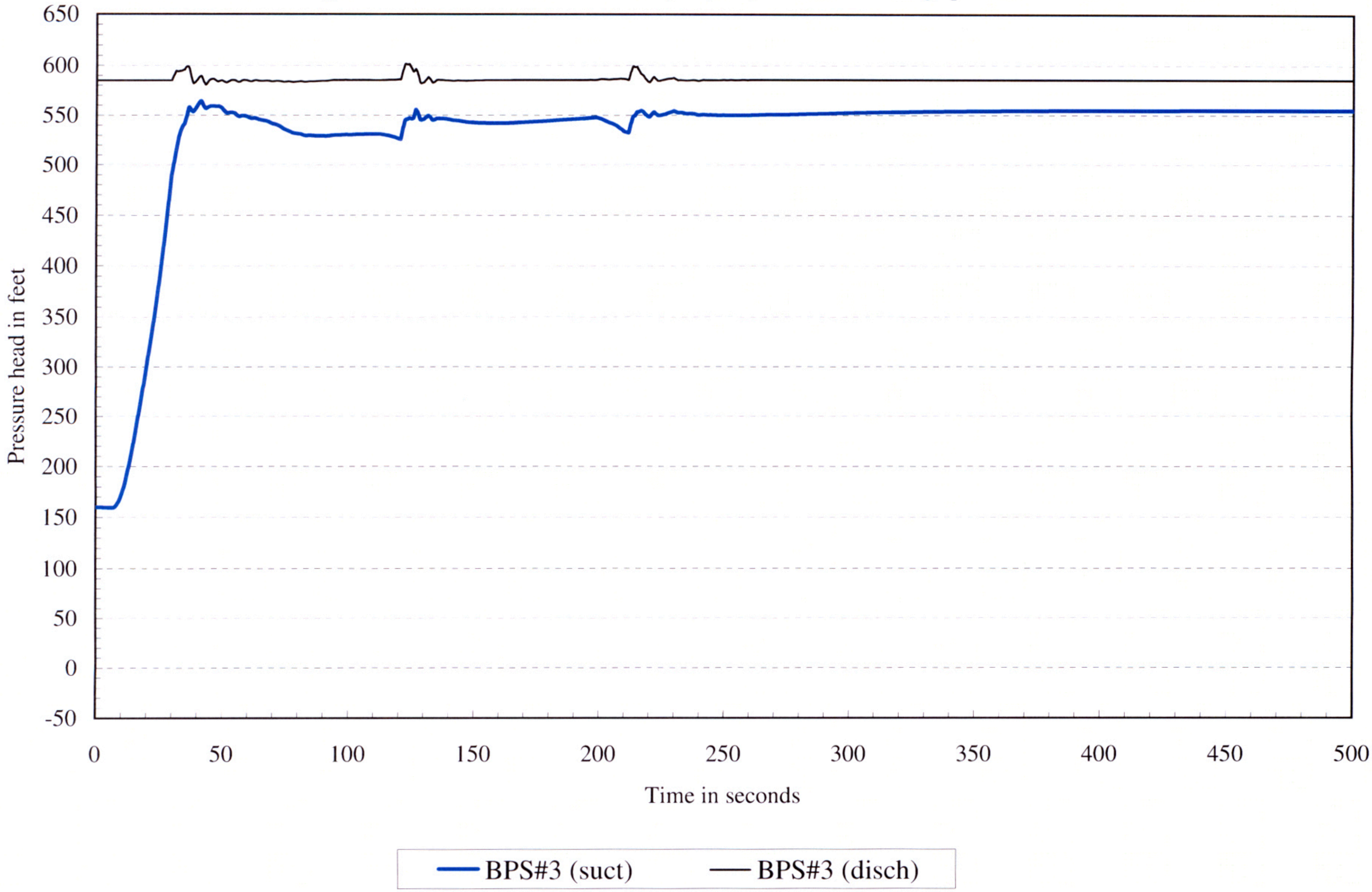
Figure 52 - Pressure heads after startup at pump stations with surge protection



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Appendix A

Predicted Maximum, Minimum & Steady State Operating Pressures
in the proposed Huntington Beach Desalination Plant
Transmission and Delivery System with surge protection installed

Location	Pipeline Pressure (psi)		
	Maximum	Minimum	Operating (maximum)
Poseidon Resources Corp. Desal Plant (HB)	224	43	224
OC-44 (196+81) - PRC pipeline tie-in	149	75	128
OC-44 (254+10) - pressure relief valve	172	69	134
OC-44 (453+08) - vacuum relief valve	124	-2	10
Huntington Beach (Santa Ana River)	188	65	150
Booster PS #2 suction (OC-44 & EOCF#2)	48	24	37
Booster PS #2 discharge (OC-44 & EOCF#2)	230	23	230
Irvine X-Feeder PCS	132	24	130
Irvine Reg. Structure	123	24	121
OC-63/OC-57	132	24	130
OC-39 (EOCF #2)	276	71	256
Booster PS #3 suction (Coastal Junction)	258	48	240
Booster PS #3 discharge (Coastal Junction)	261	166	261
Coastal Junction	262	167	262
Santiago Creek	273	234	266
CM-10 (Coastal Junction)	253	167	253
CM-12 (Coastal Junction)	253	167	253
SCWD (Aufdenkamp Transmission Main)	156	117	156
Bradt Reservoir (Joint Transmission Main)	43	43	43
Willits Street PCS (OCF)	180	76	178
Red Lion (1773+82 on OCF)	193	91	191
CM-1A (Coastal Supply Line)	88	74	88
LBCWD (Coastal Supply Line)	100	87	100